COMBUSTION

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

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Superposition—An Economic Study

Graphical Analysis of Combustion Losses

Cinder and Dust Elimination at the
Washington Heating Plant

COMBUSTION

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

VOLUME SEVEN NUMBER TWO

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FOR AUGUST 1935

FEATURE ARTICLES

EDITORIALS

DEPARTMENTS

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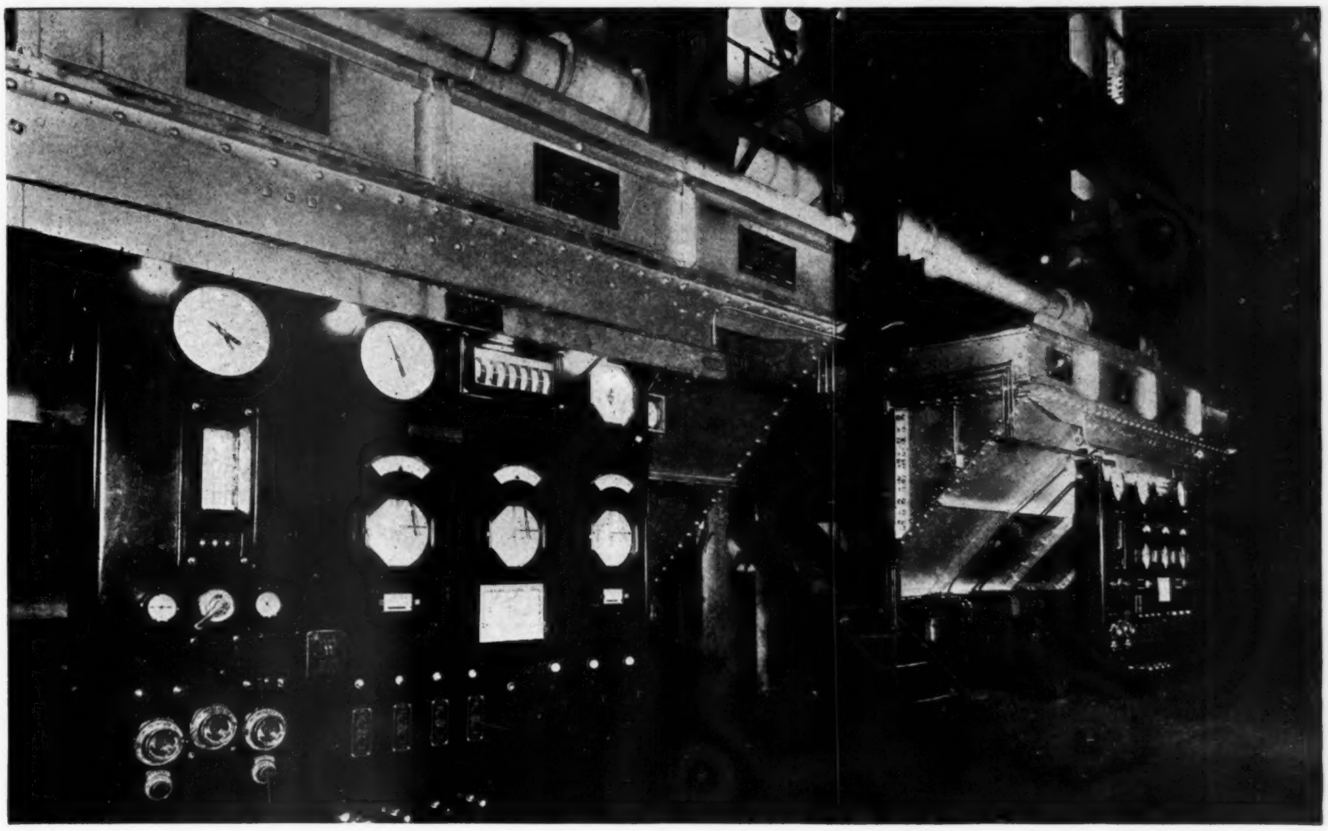

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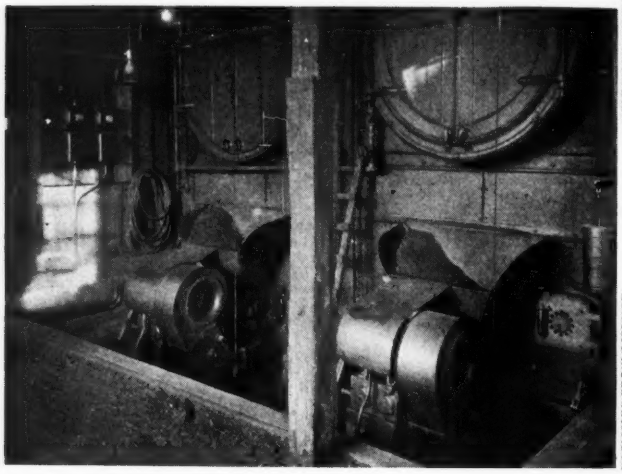

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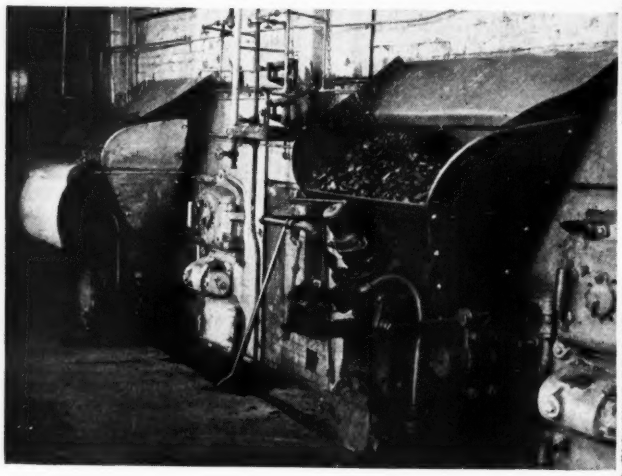

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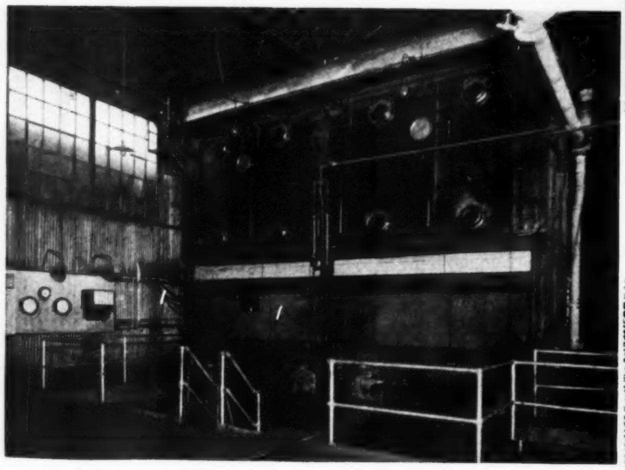

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EDITORIAL

New York to Survey Atmospheric Pollution through Federal Aid

Among the projects included in the twenty million dollars recently allotted to New York City by the Federal Government, and approved by the President, is an item of $208,680 to carry out an air pollution survey.

Compared with some other cities, New York is relatively free from objectionable smoke and other atmospheric pollution, although there is considerable room for improvement. Periodic drives have been made by the Department of Health, which is charged with enforcement of the smoke ordinance, but there has never been a comprehensive survey made of the situation. Moreover, the smoke ordinance could probably be improved by revision based on later knowledge gained from scientific investigation and experience.

If the present allottment is to be spent with the idea of achieving maximum results, and not merely as a means to help relieve unemployment, the work should enlist the aid of competent engineers, experienced in combustion and smoke abatement work, and full advantage should be taken of past research as well as of experience in other communities both here and abroad. A good example of accomplishment in smoke abatement under experienced direction is to be found right across the river from New York, namely, Hudson County, New Jersey.

To quote Dr. O. P. Hood of the U. S. Bureau of Mines: "This is a field for research which requires long-time and constant support. Temporary emergency effort over short periods cannot help much."

Looking Ahead, Regardless of Capacity Adequacy

With the continued increase in public utility electrical load, which for some weeks past has exceeded the seasonal figures of 1929 and 1930, there has been much speculation as to the ability of present capacity to meet demands in the near future, especially if industrial production should suddenly rise. In contradiction to the contentions of the National Power Survey, it appears to be the consensus among central station engineers, as expressed in recent talks and papers, that the industry, as a whole, will require little additional capacity for some time. This is based largely on the belief that it will be found economical to carry peak loads on the older and less efficient equipment and that present interconnections provide adequate flexibility in loading and sufficient reserve. Many of these engineers further concur in the opinion that station rehabilitation alone is seldom justified unless it also provides additional capacity at lower initial and operating costs. Obviously, these views are not shared by all as is reflected by a number of important installations now under construction. This emphasizes the fact that each plant and system represents an individual problem and that physical differences and local conditions render generalizations of little value.

Nevertheless, utility engineers are accustomed to look far ahead and, regardless of the ability of present capacity to meet pending demands, most central station companies have made comprehensive studies to guide them in meeting further demands. A number of these studies have favored the superimposing of high-pressure, high-temperature units on the existing low-pressure equipment. In view of this, Mr. Krieg's article on "Superposition" in this issue is especially pertinent. He outlines the various factors that must be considered in an economic study of this kind, particularly where the station is part of an interconnected system, and indicates to what extent data on the performance and experience of other stations may be useful in arriving at conclusions in the individual case. It is anticipated that his analysis will receive wide attention.

E.P.C.D. Criticized

The July issue of *The American Engineer*, journal of the newly formed National Society of Professional Engineers, scathingly indicts certain activities of the Engineers Council for Professional Development (which represents seven national engineering bodies) in its program for enhancement of the professional engineer through student selection and guidance, accrediting of engineering schools, professional training in the post-graduate period and, finally, professional recognition. It will be recalled that this work has been under way for about two years under the leadership of Dr. C. F. Hirshfeld assisted by a group of well known engineers and educators.

Particular exception is taken to the statement in a recent release by E.P.C.D. to the effect that there is no single criterion by which an engineers' qualifications can be measured and that it is proposed to define minimum qualifications of education and experience, the fulfillment of which will entitle an engineer to be recognized among his fellows and in his relations to the public.

It is the contention of the editorial that the qualifications of a professional engineer are already set up by the states that require licensing based upon examination and that E.P.C.D. is overstepping its perogatives and has no cause for existance other than as a means of temporarily gathering data. It suggests further that its recorded purposes can better be accomplished by the National Society of Professional Engineers.

While engineers are not in full agreement as to the efficacy of licensing, it is the law in many states and from a legal standpoint defines the status of the professional engineer. Perusal of literature issued by E.C.P.D. fails to disclose anything adverse to licensing. The scope of its work, however, is broader than that encompassed by licensing alone for it aims not only to enhance the status of the engineer but also, through a process of selection, guidance and training to produce better engineers.

SUPERPOSITION
—An Economic Study

By E. H. KRIEG,
Engineering Department
American Gas and Electric Company

Whether or not new capacity is required, it should be determined what opportunities exist for making a profitable investment when such need arises, and whether the situation can be met best by superimposing high-pressure equipment on existing low-pressure units, rehabilitation of existing equipment for higher pressures and temperatures or building new stations. The procedure for making such an analysis is outlined. Where there are several stations on a system the effect of changes in incremental costs, shifts in load and possible further interconnection must be taken into consideration. Data on the availability of high-pressure units are included as pertinent to the problem. The author points out that "superposition" is not new and cites the performance of several older stations that employ such an arrangement.

SUPERPOSITION of a high-pressure boiler and turbine installation in an old plant, the high-pressure turbine to exhaust to one or more existing low-pressure turbines, is not a recent idea but dates back at least to 1920 and no doubt before then. Successful service has been obtained from a number of existing plants that are fundamentally true superposed installations. Stations believed to be true cases of superposition are:

Edgar (Boston)
Deepwater (Houston Lighting & Power Co.)
Northeast (Kansas City)
Lakeside (Milwaukee)
Burlington (Burlington, N. J.)

Each of these plants not only has one or more high-pressure units exhausting into low-pressure units, but also low-pressure boilers some of which are continuously in operation as is indicated in Table I. (The order of listing these stations has been changed in the table.) It is true that some of these plants may not have adopted superposition for the express purpose of rehabilitating obsolete equipment but, aside from this fact, there is essentially nothing that distinguishes them either in point of view of design or installation from the type of plant considered for the purpose of postponing the obsolescence of existing generating equipment. There should be no impression that rehabilitating old plants by superposition is an unknown and unproved experiment.

There are also a number of other plants which differ from a superposed plant only in that there are no low-pressure boilers that might be used to run the low-pressure turbines alone, independently of the high-pressure units. These low-pressure turbines could be run independently of the high-pressure turbines and boilers if low-pressure boilers were installed. At these plants, if the high-pressure turbines fail, a pressure-reducing system automatically acts to supply steam from the high-pressure boilers at reduced pressure to the low-pressure turbines which will stay in service. Similarly in superposed plants a like system is provided, in case the high-pressure turbine is out, the low-pressure boilers are available to back-up the high-pressure boiler. So far as the turbine room is concerned, the Deepwater station in New Jersey and the 165,000-kw unit at Philo are essentially of the superposed type. South Amboy, Gilbert and Station A (San Francisco) have steeple-compounded units, the low-pressure elements of which may or may not be suitable for operating with low-pressure boilers.

At the Cabin Creek station of the Appalachian Electric Power Co., a subsidiary of the American Gas and Electric Co., there is a 5000-kw, 400-lb, 725 F, turbine that exhausts to two 250-lb, 600 F, turbines of 20,000 kw and 25,000 kw capacity. This, of course, is a true superposed arrangement installed for the purpose of postponing the obsolescence of the two 250-lb units by increasing efficiency. No special boilers were installed for this turbine as there are boilers supplying two 400-lb, 725 F, turbine-generators of 20,000 kw and 31,500 kw.

Justification by Improved Efficiency or Needed Capacity

Studies of superposed units have been made for several plants of the company with which the writer is connected, although no new capacity is needed immediately. The fundamental principle should be kept in mind at all times, that, whether a system needs new capacity or not, it should be known what opportunities exist for making a profitable investment. Even where no new capacity is needed, it should be known whether any type of rehabilitation offers justification of new investment, whether the means is superposition, rehabilitation of existing units, an extension similar to existing units, or an entirely new station. If new capacity *is* required, it is still necessary to know the best

method of adding it and to study the problem from the same viewpoint as when no new capacity is needed.

The next step is to determine what return each of the foregoing schemes offers. The two important factors are, (1) what investment must be carried (both old and new) and, (2) the old and new production costs (including fuel, labor, maintenance, etc.). The matter of investment to be carried, whether old or new, is a matter of individual determination. There are too many physical differences between plants that render investment costs impossible of accurate comparison. For instance, one plant may require absolutely nothing to be done to an existing building for the installation of the high-pressure boiler and turbine, whereas in another plant existing equipment may have to be removed and the building so remodeled that it would be cheaper to build an entirely new station. Besides this, there are as many ways of preparing a cost estimate as there are individuals to prepare it. The same applies to what proportion of old capital must be carried by the new investment.

There seems to be little to be gained in trying to compare the cost estimates of several different companies. It is well known how much investment costs vary and it is believed that the yardstick is not what some other system did but what effect a superimposed unit would have on one's own individual system. It may suffice to state that several studies show that superposed units could be installed at a cost ranging from $75 to $100 per additional kw. This is predicated solely upon the fact that the turbine-generators being considered were of large size (around 30,000 kw), that a single boiler only was considered, and that little revamping of the existing building and foundations would be required. Further, the existing turbine-generators required few or no changes to adapt them to the service contemplated.

The same difficulties exist in trying to compare estimated production costs. Large differences in production costs between plants that have practically identical equipment and operating conditions are well known, and it is therefore felt that the question of determining whether a superposed installation is justifiable rests with those individuals responsible for deciding the case for the particular installation in question. The fact that Richmond station (Philadelphia) built in 1925, actually could do 13,700 Btu per kwhr with 400 lb, 725 F, did not prevent a number of 400-lb, 725 F stations, built subsequently, from having performances of 15,000 Btu per kwhr or more.

Even with investment costs of $75 to $100 per kw and an expected improvement in economy from a present heat rate of 19,000 Btu per kwhr to 13,000 Btu per kwhr, the proposals studied were found unjustifiable from the standpoint of savings alone until new capacity should be required. In other words, until new capacity is required, the savings in production costs would not carry the old and new investment with sufficient margin of safety to warrant the adventure. The purpose of this statement is, therefore, to give our own experiences with superposition studies, to be modified by the foregoing notes of caution to those who attempt to apply these experiences to a study of a different system.

TABLE I—OPERATING DATA ON FIVE SUPERPOSED STATIONS

	Plant 1	Plant 2		Plant 3	Plant 4	Plant 5
High-pressure Boilers						
1934 hours in operation	25770	27568		......	16491	7884
1934 hours on bank	467	3610		......	None	14
1934 hours unavailable	17564	2090		......	1029	768
1934 avg efficiency, per cent	.....	86.38		85	81.4	84.0
Low-pressure Boilers						
Availability	.....	Not Determined		c	k	....
1934 avg efficiency	.....	85.82		80e	.....	71
Are l-p boilers operated while h-p boilers are on? % of time	Yes Variable %	Yes 100%		Yes 75%	Yes 100%	In general No
Are l-p boilers kept on bank to back-up h-p boilers? % of time	Yes Variable %	b		f	Yes 100%	In general No
Are l-p boilers only operated when h-p boiler is off?	No	Yes		No	.....	In general
Are l-p boilers ever operated at all?	Yes	Yes		Yes, 75% of time	Yes	Yes
High-pressure Turbines						
1934 hours in use	13263	25917.50		7000h	8668	7644
1934 hours unavailable	9135	463.0		1730	92	782
1934 hours standby (idle hours)	3882	8659.5		None	None	334
1934 generation, 1,000,000 kwhr	83.234	165.795		53.41	101.949	108.662
Low-pressure Turbines						
Average availability, per cent	85.8 84 73	91.0		......	Station 91.01	90
1934 generation, 1,000,000 kwhr	463.79	718.12733		390.892	400.633 (Total)	200.636
General						
Into what l-p turbines can each h-p turbine exhaust (give unit numbers)?	Any	Any		Any	Any	Any
Type of reheater	Gas, convection	1 Radiant	3 Convection	Radiant	Steam—Steam	None
Performance—For Year 1934						
Btu per kwhr with high pressure	13977	12847		14386 (1932 net)	14225	15616j
Btu per kwhr, only low pressure	.....	16180		17900 (1932 net)	17000	.....
Water rate with h-p (for station), lb/kwhr	9.39	9.064		9.43 (1932 gen)	10.88l	11.53
Water rate with l-p (for station), lb/kwhr	.....	11.643		11.00 (1932 gen)	12.46	.....
Per cent auxiliary power of total generation (not of net)	6.51	...... 6.37	6.40 h-p 6.26 l-p	..... 6.36i	6.8	5.82
Yearly load factor: h-p		63.51		75.5	97.1	64
l-p	55.8 (sta)	21.20		68.8		71
Yearly plant capacity factor: h-p	36.7	62.32		75.5	63.9	55
l-p	40.1	11.57		31.8	....	61
plant	.....	.....		....		59

b—No, but sufficient capacity in operation is available in case one h-p boiler is lost
c—Use only 6 of 12 boilers, so availability no item.
e—80% steaming, 78% including banks.
f—Enough steaming or banked to pick up load of one h-p boiler.
h—Unusually low because of installation of steam scrubbers in both boilers, also out 6 weeks to reconstruct packing.
i—% auxiliary power of total generation without h-p unit = 4.5%.
j—Best month to date, 14820, March 1934.
k—Availability higher than usual because usual overhaul period not included in this period.
l—Includes steam for condensing reheaters.

Some of the factors influencing a decision, other than the investment and old versus new production costs, are:

1. Effect of Incremental Cost Changes

Where there are several stations on the system, any of the possible changes (superposition, rehabilitation of existing units, extension similar to existing stations, or new stations) causes a change in the incremental costs of the station being studied. It then becomes necessary to estimate the load shifts between the stations resulting from the change in incremental costs, and to estimate new outputs in each station to determine the true savings. These include a study of production costs, load factors, etc. This portion of the work is probably the most complicated of all, as may be appreciated by referring to the literature that has been published on incremental costs. It should be kept in mind that the saving made by a superposed unit is *not* the difference between the old and new costs for that station, but may be between the costs of another station and the new superposed installation if load has been shifted from the other station to the new station.

TABLE II—HIGH PRESSURE UNITS (AROUND 1200 LB)

							Factors, Per Cent						
System	Unit No.	Size Kw	Year	Unit Cap	S. D. Avail	Unit Oper	Turb Out	Gen Out	Cond Out	Other Causes	Res	Make, Type Service	Hr Insp
35	8	10,000	1933	13.83	100.00	15.37	1.67	0	0	1.55	81.41	A-S-2	0
			1931	25.28	87.97	31.63	18.35	0	0	0	55.02	....	..
62	4	50,000	1933	14.00	100.00	79.57	15.97	0	4.46	0	0	A-VC-2	1394
			1932	15.42	90.65	90.65	0.18	3.55	0	5.62	0	....	0
62	3	50,000	1933	14.72	100.00	85.36	14.37	0	0.27	0	0	A-VC-2	1256
			1932	15.13	88.45	88.45	0	5.48	0	6.07	0	....	0
67	3	12,000	1933	26.31	62.29	62.29	24.72	0	0	9.44	3.55	B-CC-3	814
			1932	21.21	70.50	47.74	5.71	0	0	36.04	10.61	1-2	0
35	7	3,360	1933	30.30	59.08	47.31	6.29	0	0	28.86	17.54	A-S-3	551
			1931	34.73	64.88	58.26	0.05	0	0	35.80	5.89		
35	9	12,500	1933	55.80	92.95	81.43	4.85	0	0	1.79	11.93	A-S-2	0
			1931	41.04	99.14	70.21	20.11	0	0	0.45	9.23		..
50	10	7,700	1933	57.05	98.35	72.48	2.37	0	0	0	25.15	A-S-2	204
			1932	55.82	99.10	68.33	1.29	0	0	0	30.38	....	0
			1931	59.62	97.57	66.64	5.90	2.40	0	0	25.06		
50	8	7,700	1933	58.07	100.00	72.78	0.07	0	0	0	27.15	A-S-2	0
			1932	48.08	97.40	61.00	1.46	0	0	2.66	34.88	....	0
			1931	58.20	93.35	69.34	8.40	0	0	0	22.26	....	0
50	12	7,700	1933	61.13	100.00	75.85	0	0	0	0	24.15	A-S-2	0
			1932	59.75	98.50	74.52	3.28	0	0	0	22.20	....	288
			1931	55.51	94.97	64.96	10.20	0	0	0	24.84	-3	
50	9	7,700	1933	61.67	98.83	76.98	0	1.19	0	0	21.83	A-S-2	0
			1932	56.10	98.00	71.95	4.11	0	0	0	23.94	....	0
			1931	58.52	95.38	69.36	3.20	0	0	3.0	24.44	-3	
13	6	10,000	1933	70.68	87.49	87.42	7.03	0.21	0	5.27	0	B-S-3	597
			1931	48.81	67.12	67.12	28.11	3.74	0	1.03	0		
34	6	12,000	1933	76.95	93.01	93.01	2.37	0	0	4.62	0	A-S-3	0
			1932	54.13	70.79	70.80	24.36	0.09	0	4.75	0	....	0
75	1	12,500	1933	77.25	94.48	94.48	5.40	0.12	0	0	0	A-S-3	377
			1932	64.54	97.30	97.30	2.45	0.16	0	0.09	0	....	213
			1931	71.38	97.14	97.14	2.50	0	0	0.35	0		
75	3	11,000	1933	84.20	94.25	89.50	6.55	0.07	0	0.52	3.36	A-S-3	438
			1932	83.08	94.40	91.20	3.83	0	1.29	0.43	3.25	....	266
			1931	79.00	93.40	92.43	6.40	0	0	0.26	0.91		
75	4	11,000	1933	88.32	95.05	90.37	5.01	0.03	0	0.81	3.78	A-S-3	354
			1932	86.40	95.40	91.54	4.00	0.26	0.16	0.19	3.85		228
			1931	71.27	78.98	78.18	20.60	0	0	0.22	1.00		
31	2	11,800	1932	46.32	77.80	77.78	0.49	0.03	0	0	21.70	A-S-3	0
			1931	65.65	95.43	93.39	4.44	0	0	0.03	2.14		
Avg	15	15,544	1933	52.69	91.72	74.95	6.44	0.11	0.32	3.52	14.66	....	..
	12	17,425	1932	50.49	88.36	77.60	4.26	0.80	0.12	4.65	12.57	....	..
	12	9,413	1931	55.58	88.78	71.55	10.28	0.51	0	3.43	14.23	....	..

The figures in Table II were taken from the E.E.I. and N.E.L.A. "Turbines" Reports of July 1932, August 1933 and June 1934. The column headings are:
Unit Capacity Factor—Ratio of kwhr generated to product of unit rating and total hours in year.
Service Demand Availability Factor—Ratio of service hours to demand hours.
Unit Operation Factor—Ratio of service hours to total hours per year.
In next to the last column: A and B indicate make; S—single cylinder, VC—vertical compound, CC—cross compound; 1—peak loads only on reserve for other generating units; 2—average centrol station load demands on daily peak load type; 3—continued base load service.

2. Possible Connections with an Industrial

The effect of connections with large industrials or other systems must be considered.

3. Miscellaneous

All factors likely to affect the decision to construct or not to construct a new station must, of course, be considered, such as fuel supply, load center, etc.

4. Availability

The anticipated availability of the high-pressure boilers and turbines is most important from the viewpoint of how much the output will be affected by outages. Such data are available for turbines in the various reports by the Turbines Subcommittee, and for boilers in the study by Messrs. Hirshfeld and Moran, and in various N.E.L.A. and E.E.I. reports. These data are available, not only for the low-pressure units but also for higher pressure units such as are now being considered in connection with superposition.

The most important factor given in the various Turbines Reports is probably service demand availability which indicates the percentage of the time the turbine is available when needed. In Table III it is seen that this factor for 550 to 1000-lb turbines was as follows:

Year	Service Demand Availability Factor, per cent
1925	90.93
1928	94.90
1929	96.90
1930	95.81

In Table II for turbines of around 1200-lb pressure it is seen that this factor has ranged as follows:

Year	Service Demand Availability Factor, per cent
1930	82.68
1931	88.78
1932	88.36
1933	91.72

TABLE III

	Pressure 550-Lb Gage to 1000-Lb Gage				1000-Lb Gage or Above
	1930	1929	1928	1925	1930
Turbines units reviewed	17	17	12	7	10
Average capacity of units, kw	58,294	64,880	56,700		10,056
Service demand factor, %	84.40	86.05	86.70	75.39	86.87
Service demand availability factor, %	95.81	96.90	94.90	90.93	82.68
Unit capacity factor, %	57.42	60.66	65.50	39.80	51.28
Unit output factor, %	71.01	68.75	73.90	58.40	71.39
Service hours, factor, %	80.87	83.34	82.40	68.10	71.82
Total outage factor, %	10.71	12.24	11.73	24.67	19.75
Turbine outage factor, %	4.32	4.76	5.60	14.75	10.68
Generator outage factor, %	1.21	1.17	0.54	3.72	0.48
Condenser outage factor, %	4.52	4.48	5.02	1.891	
Other causes outage factor, %	0.66	1.83	0.57	4.235	8.59
Reserve hours factor, %	8.42	4.42	5.87	7.23	8.43

The figures in Table III were taken from the N.E.L.A. "Turbines" Reports of August 1931, August 1930, August 1929 and July 1927. The factors are:
Service Demand Factor—Ratio of demand hours to hours per year.
Unit Output Factor—Ratio of kwhr generated to product of unit rating and service hours.
Other factors are same as given in Table II for 1932, 1933 and 1934.

It must be realized (and can readily be seen from Table II) that the foregoing ratios could have been much higher except for a comparatively few turbines which had an exceptionally low factor that pulled the entire average down. For example, in 1933, there were five turbines with 100 per cent demand availability and seven more that ranged from 92.95 to 98.83 per cent, a total of twelve out of fifteen. In 1932, eight turbines out of twelve were 90 per cent or over, and in 1931 eight turbines out of twelve were 90 per cent or better.

From Tables I, II and III, especially considering the improvement in turbine design that has occurred since these turbines were installed, it appears as though a turbine service demand availability factor of 92 per cent or more may confidently be expected even with these old designs. For new turbines it is believed that a turbine availability of 95 per cent is not unduly optimistic, as will be seen from the record of the following four turbines:

Year	Unit 50-10	Unit 50-8	Un't 50-12	Unit 50-9
1933	98.35	100.00	100.00	98.83
1932	99.10	97.40	98.50	98.00
1931	97.57	93.35	94.97	95.38

Of course, service demand availability is affected by the number of turbines on the system, permitting outages when there is no demand. An isolated plant could not use the above factors. There is little use to compare unit capacity factors because these are a function of system requirements.

As for boiler availability, few can attain the factors of 97.6 per cent for 1933, 93.7 per cent for 1932 and 93.6 per cent for 1931 as did Lakeside. However, from our own experience, it is believed that 90 per cent can be attained regularly with 1400-lb boilers.

A superposed installation can therefore be considered to have an availability of 0.95 × 0.90 or 85.5 per cent. There is little doubt but that this might be improved to 90 per cent by coincident boiler and turbine outages.

With availabilities as given, there seems little need of duplicate high-pressure boilers or turbines on an interconnected system. This is particularly true in cases where low-pressure boilers are available for the low-pressure turbines, making it possible to remove the high-pressure equipment from service during the periods when a large amount of surplus capacity is available.

Comparing Alternatives

In studying the superposition possibilities for a given station, a tabulation such as the following is the fundamental basis of comparison. This is shown for a comparison between two stations, A and B, and considers not only superposition but also what may be done in the way of rehabilitating existing units, an extension along the same lines as the existing station, and the possibility of a new station.

	Existing System	New System Superposition	Rehabilitation	Extension	New Station
Station Name	A,B, A&B	A,B, A&B	A,B, A&B	A,B, A&B	A,B, A&B
Yearly kwh					
Production costs, mills /kwhr					
Savings (diff. bet. existing and new) mills /kwh	X X X				
Yearly Savings $	X X X				
Investment Carried:					
New	X X X				
Old (existing equip. not retired)					
TOTAL					
% Return					

Of course, the study is a great deal simplified if only one station is under consideration, as it is not necessary to examine the involved incremental studies for all stations to get the lowest net incremental for the entire system. The figures given in the superposition column would be the best selection from a number of different cycle possibilities using a superposed unit. If the old station operated at 250 lb, 600 F, which is the average throttle condition for old stations of this company, cycles with superposed units are considered for the following throttle conditions on the high-pressure unit: 400 lb, 750 F; 600 lb, 800 F; 1200 lb, 900 F.

TABLE IV

Boiler No.	17	18	19	20	All
Hr operated, per cent					
1931	73.1	67.8	72.4	74.0	71.8
1932	58.4	76.6	76.5	70.2	70.4
1933	75.8	81.5	81.4	80.9	79.9
No. times banked					
1931	177	201	233	232	843
1932	253	242	253	290	1038 (22 per mo.)
1933	202	233	224	230	889 (18.5 per mo.)
Banked hr, per cent					
1931	8.2	9.7	11.8	11.9	10.4
1932	14.1	13.5	14.1	16.7	14.6
1933	12.1	13.4	12.1	14.1	12.9
Idle hr, per cent					
1932	11.2	7.9	5.8	10.0	8.7
1933	8.2	3.6	4.1	3.2	4.8
Repair hr, per cent					
1931	10.1	7.8	5.45	2.4	6.5
1932	16.3	2.0	3.6	3.1	6.3
1933	3.9	1.5	2.4	1.8	2.4
Available hr, per cent					
1931	89.9	92.2	94.6	97.6	93.6
1932	83.7	98.0	96.4	96.9	93.7
1933	96.1	98.5	97.6	98.2	97.6

The data in Table IV on the four 1390-lb boilers at Lakeside were taken from the January 1933 "Boilers, Superheaters and Economizers" Report, and the August 1934 "Steam Generation" Report. The availability factor of 97.6 per cent for all four high-pressure boilers for 1933 is high and cannot be attained in the average station.

Under rehabilitation of old units, the possibility of remodelling existing turbines for higher pressures and temperatures has been examined; also remodelling the low-pressure turbines for still lower pressures (say, from an original 250 lb to 50 lb) to pass large quantities of steam so as to obtain the maximum heat drop and capacity from the high-pressure unit. The old boilers would be used with new higher temperature superheaters and a new turbine for the original pressure but higher temperature. It has been our experience that such remodelling is not as economically justifiable as a high-pressure superposed unit, although it must be remembered that this is not necessarily true for all cases.

Where stations have been analyzed that already operate at 600 lb, 725 F, superposed units were not thought justifiable. An extension at 600 lb, 900 F appeared to be the best alternative. There is an insufficient gain above 600 lb to warrant changing the pressure, whereas maintaining the same pressure makes it possible to exchange steam between the new boiler (although at a higher temperature) and the existing boilers, thus increasing the availability of the new turbine in case boiler outage does not exactly coincide with new turbine outage. The 725 F boilers could run the 900 F turbine, and the 900 F steam would be tempered to 725 F to run the 725 F turbines. However, it has been found that there is a distinct gain in going to a higher temperature in order to eliminate reheat. It should be emphasized, at this point, that reheat cycles offer no serious difficulties in operation, and that we do not believe there is justification for statements that a reheat cycle is much more complicated and more troublesome to operate than a non-reheat cycle. At the present time, The American Gas and Electric Co. has four plants using the reheat cycle: Philo, Deepwater, Stanton and Twin Branch.

It is the consensus of opinion of the operators of these stations that they have no more trouble with the reheat cycle than with the 250-lb, 600 F cycles which were used in the stations they operated before the reheat stations were built. The only reason that the reheat cycle is not being considered in present studies is because it does not offer as high a financial return as does the 900 F non-reheat cycle.

As far as the possibility of building entirely new stations in different localities is concerned, it is believed that the possibilities inherent in superposition and 600-lb, 900 F extensions to existing 600-lb, 725 F plants would far outweigh the advantages that would be gained by going to a new site.

Table V summarizes briefly the 1250-lb, 900 F study made for one plant:

Firm boiler capacity of 50,000 kw is installed in 250-lb pressure units giving sufficient steam requirements for all 250-lb turbines when the single 1200-lb boiler would be down.

In this particular case, a 1200-lb, 900 F cycle was found to be most economical, the high-pressure turbine exhausting at from 225 to 255 lb absolute back pressure. The performance of the existing turbines and boilers is about 19,000 Btu per kwhr output.

TABLE V

Scheme	1	2	3	4
New h-p unit, kw	30,860	36,100	36,000	31,200
Old unit No. 1	27,230	27,775	27,490	27,490
Old unit No. 2	22,165	22,500	22,330	..
Other old units,	..	..	12,000	16,000
boiler feed pump, turbine	1,800	1,900	2,000	1,700
Total generation, kw	82,055	88,275	99,820	76,390
Firm capacity, h-p unit out	49,395	50,325	50,000	43,490
Firm capacity, h-p and largest 1-p out	22,165	22,550	38,330	16,000
Kw net output	75,000	81,000	92,000	70,000
Pounds steam/hr	750,000	795,000	950,000	700,000
Throttle heat, Btu/lb	1,460	1,460	1,460	1,460
Feed heat, Btu/lb	360	340	360	340
Heat added/1-p Btu	1,100	1,120	1,100	1,120
Btu per kwhr output, 75 per cent boiler eff	13,100	12,950	13,350	13,200

Quality of Anthracite

At the request of the Anthracite Institute, the United States Bureau of Mines recently made a three-months' field survey of commercial anthracite shipped from collieries scattered throughout the anthracite regions, the results of which are published in the Bureau's "Report of Investigations, No. 3283."

In all, 268 samples were taken at 41 breakers from Carbondale at the northern end of the field to Pottsville at the south. These collieries ship approximately 50 per cent of the industry's total production. The following tabulation gives the weighted average analyses, by sizes, of the samples taken in this survey:

		Dry Coal				B.t.u.			Soft'ng
Size	Moisture as Rec'd.[1]	Vol'tl. matter	Fixed Carbon	Ash	Sulphur	As Rec'd[1]	Dry Coal	Moisture and Ash Free	Temp of Ash, ° F[2]
Egg	4.2	4.4	86.4	9.2	.7	13,100	13,670	15,060	2890
Stove	4.3	4.4	86.3	9.3	.7	13,040	13,630	15,030	2890
Chestnut	4.8	4.3	86.0	9.7	.7	12,900	13,550	15,010	2890
Pea	6.2	4.3	84.4	11.3	.7	12,470	13,290	14,980	2890
Buckwheat	6.0	4.6	83.7	11.7	.7	12,430	13,220	14,970	2880
Rice	5.7	4.5	83.1	12.4	.7	12,330	13,080	14,930	2900
Barley	7.2	4.4	82.1	13.6	.7	11,980	12,890	14,920	2880

[1] These samples were taken as the coal came from the breakers immediately after washing. Therefore, "moisture as received" includes, in addition to inherent moisture of about 2 per cent, the moisture due to water clinging to the coal from the washing process. In a short time after loading much of the free moisture drains off so that coal delivered to the consumer would have a heating value, according to size, between 175 and 350 Btu per lb higher than shown in the column "Btu as received."

[2] Softening temperatures of ash given are averages of determinations which include numerous "plus maximum readings" which range between 2490 and 2970 F. The actual average softening temperature is somewhat higher than those given in the table.

These figures for anthracite give a very fair picture of the quality of the product available to the public in 1935 from breakers of the anthracite industry. They should be used in making general comparisons with other fuels and with other anthracite products.

Dr. Everett P. Partridge, since 1931 supervising engineer of the U. S. Bureau of Mines Experiment Station at New Brunswick, N. J., and well known for his researches in boiler feedwater, has been appointed Director of Research of the Hall Laboratories, Pittsburgh. In this capacity Dr. Partridge will be associated with Dr. R. E. Hall, Managing Director of the laboratories.

Irving Moultrop, chief engineer of the Edison Electric Illuminating Company of Boston, retired from active service on August, after 43 years continuous service. Mr. Moultrop has long been active in both the A.S.M.E. and the A.I.E.E. and was one of the original members of the Prime Movers Committee.

Professor W. T. Magruder, for many years head of the department of mechanical engineering at Ohio State University and an active member of the A.S.M.E. for more than fifty years died at Columbus, O., on June 21.

Cinder and Dust Elimination at the Washington Heating Plant*

By F. P. FAIRCHILD and C. F. DIXON
United Engineers & Constructors Inc.

This is a two-stage system consisting of a cinder trap to remove the coarser particles and an electrostatic precipitator to remove the finer particles. The precipitators are arranged so that the flow of gas is vertical and the gas passages are of iron plate instead of concrete, as usually employed. Tests over a wide range of coal burning rates on the stokers showed efficiencies for the system from 89.2 to 94.9 per cent.

CONSTRUCTION of the Central Heating Plant for Public Buildings in Washington, D. C., involved a problem in cinder and smoke elimination requiring a more effective and reliable solution than is ordinarily encountered. The plant was to supply steam for heating and other uses to practically all the public and semi-public buildings in the "Triangle District." Considerations as to convenience of steam distribution, availability of property and proximity of fuel supply made it necessary to locate the plant quite close to the "Triangle District." A large boiler plant was necessary in which great quantities of fuel would be burned and a design was required which would discharge practically no soot or cinders to the atmosphere. The public buildings of white limestone, granite and marble could not be subjected to an atmosphere laden with cinders and soot. Trees, flowers and other vegetation would be damaged by the material ordinarily discharged from boiler plant stacks.

Various considerations unrelated to the subject of this discussion dictated a stoker-fired plant but contributory to that choice was the fact that it was believed that removal of material from the stack gases could more reliably be accomplished with stoker firing than if pulverized fuel were adopted. With stoker firing a static cinder trap may be installed which will remove a considerable proportion of the entrained material under any conditions. This type of equipment is practically useless with pulverized fuel. Some form of hydraulic

* From a paper presented at the Annual Meeting of the National District Heating Association, Philadelphia, June 11–14, 1935.

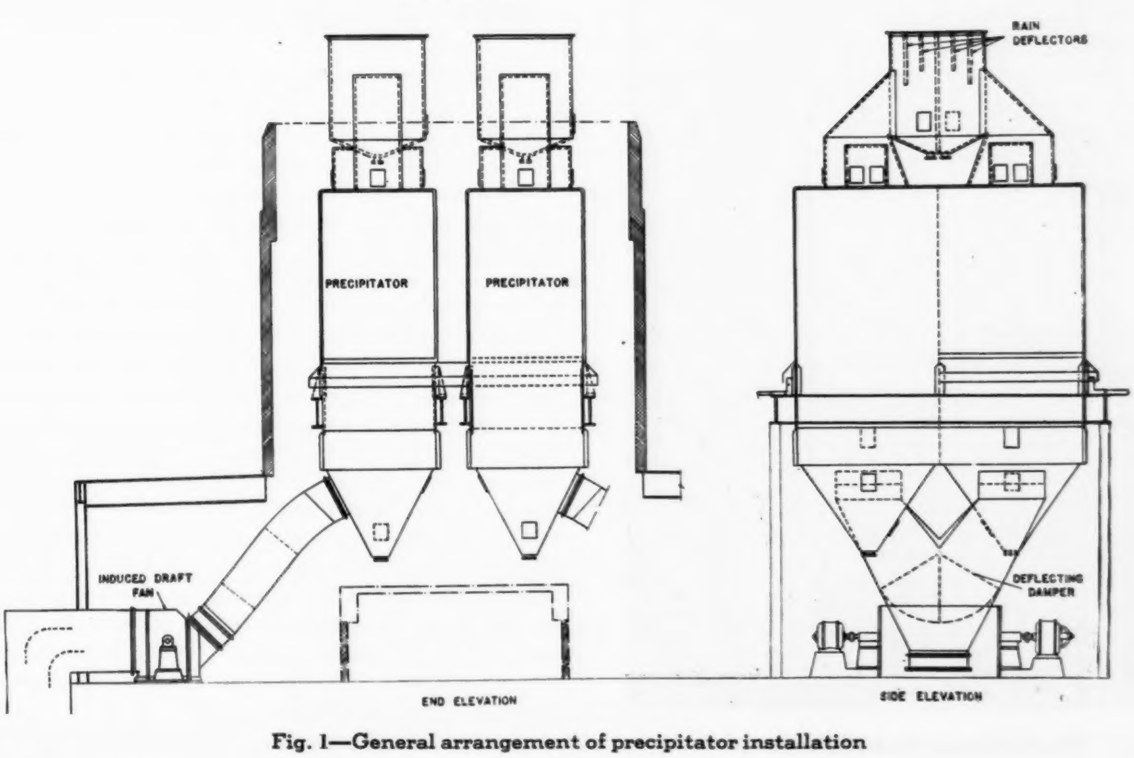


Fig. 1—General arrangement of precipitator installation

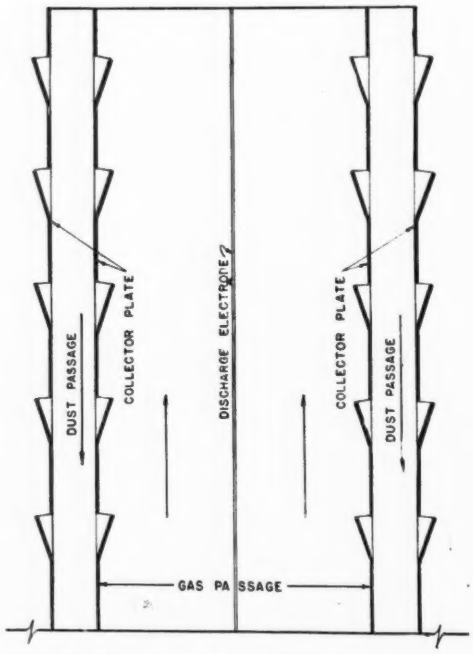


Fig. 2—Diagram of precipitator elements

or electric eliminator is necessary which is subject to possible failure at times, and failure of the system permits all of the fly ash to escape from the stacks. Both gas and oil firing were considered and rejected because of the high price (then present or probable) of these fuels.

The capacity of the boilers was chosen so that the maximum rate of fuel burning per square foot of grate area would not be so high as to cause an excessive amount of cinders and coal particles to leave the fuel bed and be carried up through the boilers. However, with the fuel

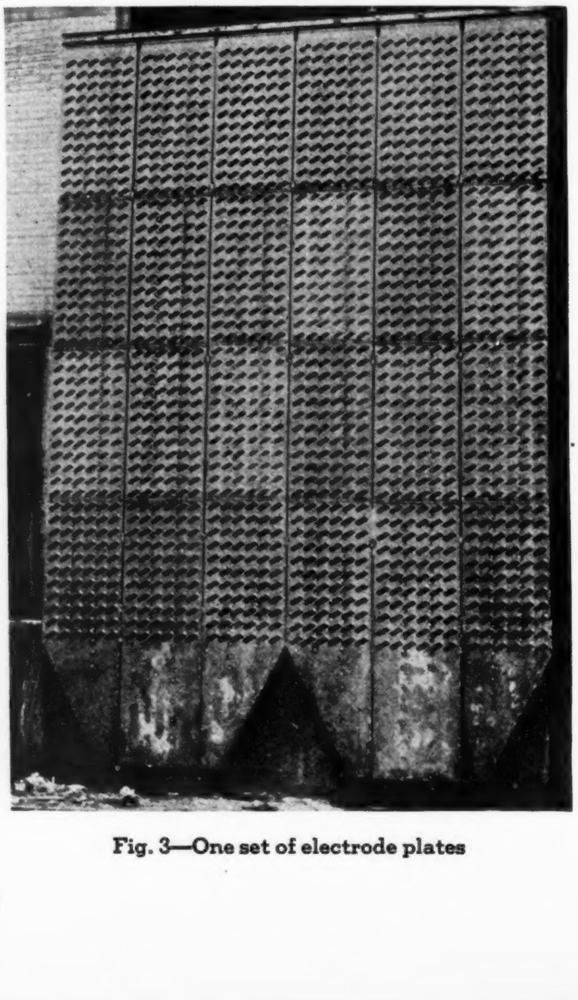


Fig. 3—One set of electrode plates

burning rate kept down to the economic minimum there still would be an objectionable emission of cinders and dust. It, therefore, was considered necessary to install cinder-eliminating equipment that as nearly as possible would remove all cinders, dust and soot from the stack gases.

It was concluded that a two stage system would be necessary to assure absolutely clean flue gases. The first designs contemplated a baffle type cinder catcher to remove coarse material followed by a wet scrubber to eliminate the fine material. Previous experience with the baffle type cinder catcher had demonstrated its efficiency for removing the coarser material. The wet scrubber while considered satisfactory from the standpoint of its ability to remove the fine material was open to two serious objections, first, under certain atmospheric conditions the cooled, moisture laden gases would flow downward after leaving the stacks, damage the build-

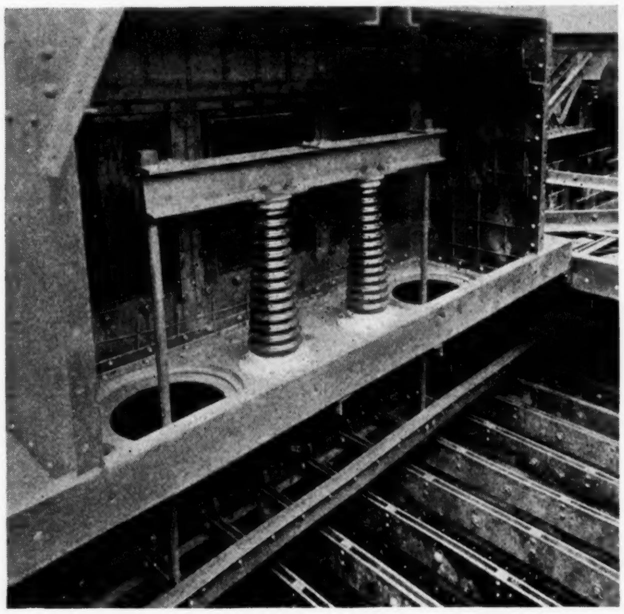


Fig. 4—Top of precipitator with insulators and hangers

ings, foliage, etc., and objectionable fumes would enter the buildings through open windows; second, the dense vapors would be visible in cool weather and be objectionable from the standpoint of appearance. Further consideration of the matter led to the conclusion that a second stage consisting of electric precipitators would be most likely to produce satisfactory results.

The general arrangement of the precipitators is shown in Fig. 1. The space available for the installation was limited and required a very compact arrangement.

This precipitator is of a new design employing some novel and interesting features. While the design has been used in Europe and its merit demonstrated, only two of the six boilers have so far been equipped. It was desired to be sure that performance would be satisfactory before installing precipitators on all boilers. Experience and tests have demonstrated the efficacy of the equipment and the other boilers are now to be provided with precipitators.

In precipitators heretofore used for pulverized fuel the gas passages have generally been of concrete in which the collecting electrodes were imbedded and the

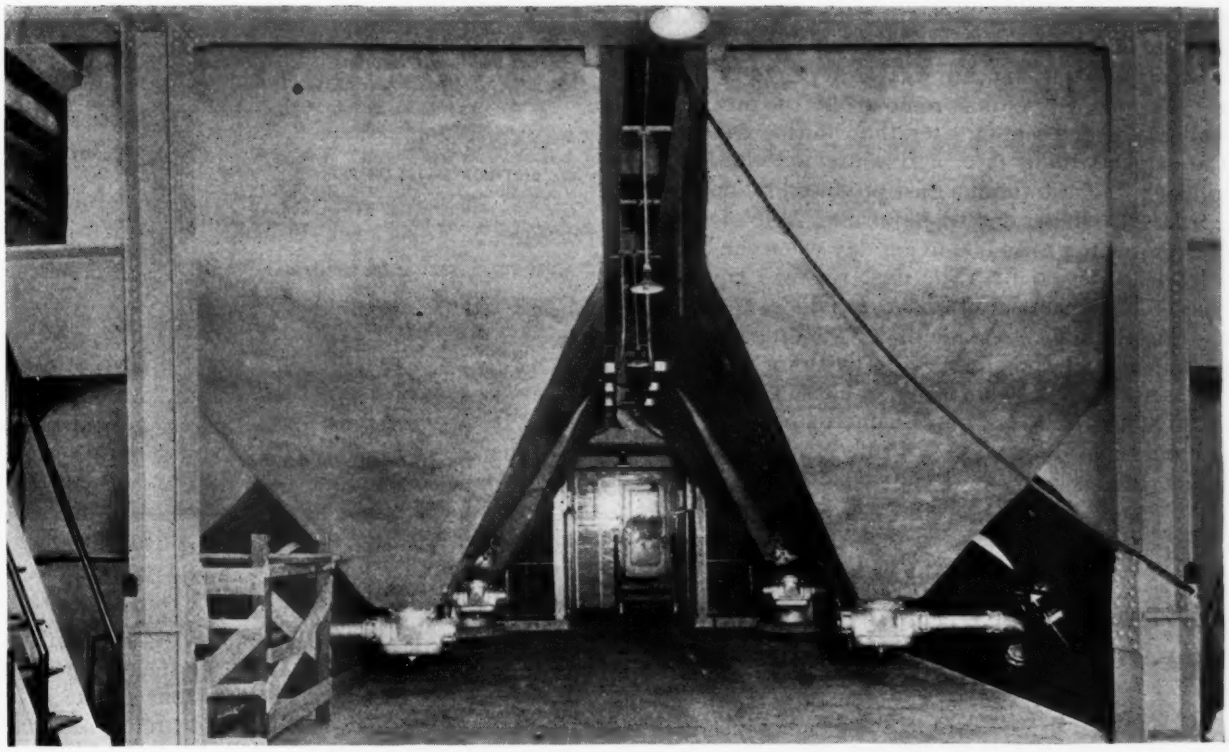


Fig. 5—Finished precipitator bottoms and vacuum system valves

flow of gas was horizontal. Drag chains moved against the sides of the gas passages, dislodged the adhering dust particles which then dropped to the hoppers at the bottom of the passage. In the precipitators at Washington the gases pass through vertically instead of horizontally and the gas passages are of iron plate instead of concrete. As shown somewhat diagrammatically in Fig. 2, the body of the precipitator consists of a number of vertical gas passages within which hang the discharge electrodes. The plates forming the sides of these gas passages constitute the collecting electrodes. The gas passages between the faces of the collecting electrode plates are $11^1/_4$ in. wide and the plates are $1^1/_2$ in. back to back leaving a quiescent space between them. Fig. 3 shows one set of electrode plates assembled. It will be seen from these two figures that the plates have louvre-like slots punched in them with the openings upward so that dust collected on the surfaces will when dislodged fall through the slots into the dead space between the plates. In operation the particles of soot entrained in the stack gases are negatively charged by the high potential in the discharge electrode wires. This charge causes them to be attracted to the plates which are of positive polarity with respect to the discharge electrodes. These plates are jarred intermittently by a motor-driven rapping device which dislodges the particles adhering to them. The particles fall into and through the slots and thence down through the dead spaces between the plates to collecting hoppers at the bottom of the precipitators. From this point the dust is conveyed by a pneumatic system to the station ash disposal system. Fig. 4 shows the top of the precipitator with discharge electrode insulators and hangers and the slots in the collector plates.

The precipitator on one of the boilers was carefully tested at four different rates of operation. Three points showed elimination of 93.3, 94.8 and 94.9 per cent. The fourth point was taken under very unfavorable and unusual conditions of operation and showed an elimination of 89.2 per cent. The curve Fig. 6 shows the dust and cinder removal by the system at different rates of firing. It will be noted that the efficiency of the precipitator is substantially constant over the range of operation shown.

The tests brought out some interesting characteristics of this installation. When operating at a relatively low rate, 23 to 24 lb of coal per sq ft of grate area, the dust removed from the precipitator was light and somewhat fluffy and weighed about 7 lb per cu ft. When operating at a higher rate, 40 to 45 lb per sq ft of grate area, the precipitator dust was much heavier, averaging 30 lb per cu ft. The power required was about 6 to 8 kw per boiler.

During one of the preliminary boiler tests CO_2 was about $15^1/_2$ to 16 per cent and the condition of the fire indicated considerable smoke. The stack however

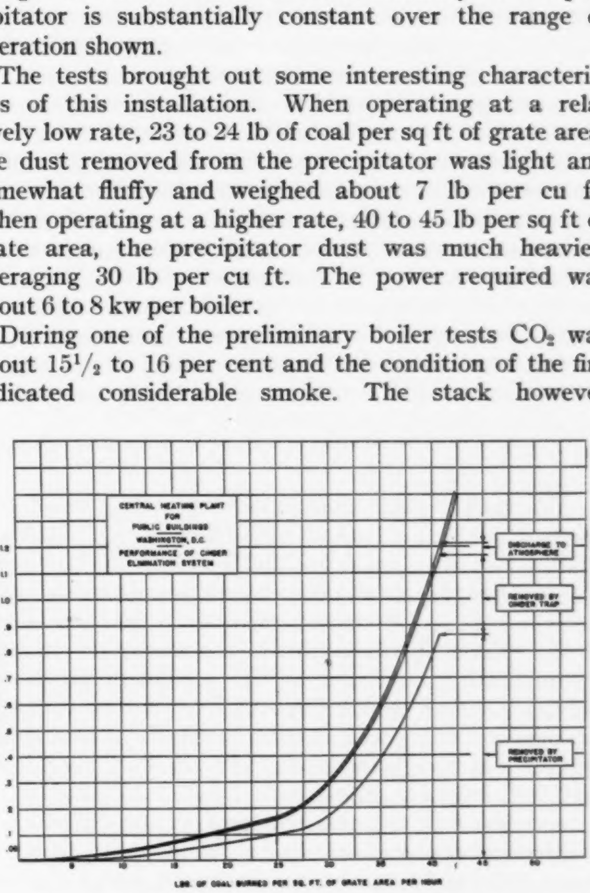


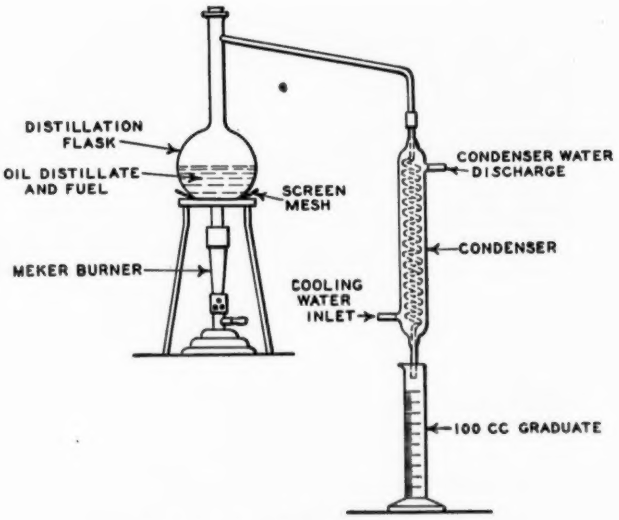
Fig. 6—Performance of cinder elimination system

was clear during this run, indicating that the precipitator was taking out smoke as well as dust and cinders. During this run the burning rate was 24 lb per sq ft of grate area. The quantity of dust removed by the precipitator was about 75 per cent greater than during other tests at the same burning rate, and contained considerable lamp black. The total flue dust produced by one boiler runs from 2000 lb per day when burning 24 lb of coal per sq ft of grate area to 14,000 lb per day when the burning rate is 45 lb per sq ft. The dust removal equipment catches 96 to 97 per cent of this material.

This installation was made under the direction of the Procurement Division, Public Works Branch, Treasury Department, N. S. Thompson, Chief of Mechanical Division and E. W. Goodwin, Engineer in Charge. The design and supervision were by United Engineers & Constructors, Inc.

Convenient Method of Determining Moisture in Coal

By WALTER H. WOOD,
Combustion Engineering Co., Inc.



Set-up for distilling moisture

THE results of tests of coal-fired steam generating equipment are affected, more than many engineers realize, by the method used in determining the moisture in the fuel. This is particularly true in the case of fuels having high moisture contents, such as lignite and the small sizes of anthracite. The amount of moisture in a coal governs its heating value. Therefore, if an error is made in the determination of moisture, there is a corresponding error in the heating value, and efficiencies based on such heating values are not correct.

Too often coal sampling is done in such a manner as to offset to some extent the care used in obtaining other important data during a test. In many instances, a laboratory may report incorrect moisture, due to improper methods, or to carelessness or indifference in handling the samples. The errors in making moisture determinations of coal samples are for the most part in one direction. Less moisture is likely to be reported by a laboratory than is actually in the fuel as fired. Heating values in such cases will be too high; efficiencies on evaporation tests will be low, and on heat balance tests, they will be high.

A method of determining moisture in fuel, which combines speed and accuracy, is to remove the moisture by distillation, then condense and measure it. By use of this method, the total moisture in a sample of fuel can be determined every hour, or more often if desirable, during a test. The apparatus used in making the moisture determination is shown in the accompanying sketch. In determining moisture by this method, a sample of 250 grams of the coal as fired is weighed, then quickly placed in a distillation flask, and the flask filled about half full of light oil distillate. The side tube of the flask is connected to a condenser, and at the outlet of the condenser is placed a 100 cc graduated cylinder. A flame from a Meker burner is placed under the flask. Some of the distillate is first distilled and condensed, and collects in the graduated cylinder. As distillation proceeds moisture is distilled from the fuel, condensed and passes through the oil to the bottom of the cylinder. Distillation is carried on until no water is seen passing downward through the oil in the cylinder. The quantity of water is easily read, as there is a sharp line of demarkation between the oil and the water. The percentage of moisture in the fuel is the quantity in cubic centimeters divided by 250.

In using a sample of 250 grams for distillation a slight error in weighing will not affect the result materially. For example, if the amount of water obtained by distilling 250 grams of coal is 12. 5 cc, the amount of moisture in the sample is $\frac{12.5}{250}$, or $12.5 \times \frac{4}{100} = 5$ per cent. Because of the large sample used, a small error made in weighing the sample will not affect the percentage of moisture materially.

The following tabulation shows the moisture determined by both the well-known bag method of air drying, and by the distillation method, on three eight-hour tests, when burning Texas lignite.

	Test 1		Test 2		Test 3	
Method of determining moisture	Air drying	Dist'n	Air drying	Dist'n	Air drying	Dist'n
Total moisture in fuel, per cent	32.17	33.38	32.97	32.47	32.97	33.49

It will be noted that the distillation method showed higher moisture content on the first and third tests, while on the second test the moisture by air drying was 0.5 per cent higher than by distillation.

The temperature in the flask during distillation usually ranges between 450 F and 475 F. Some volatile matter in the fuel may be driven off during distillation, but that apparently does not affect the moisture content.

The oil distillate can be decanted and used again. Kerosene is not satisfactory as too violent boiling occurs, while moisture is being driven off.

The equipment needed for making moisture determinations in this manner is simple and inexpensive. Care, rather than skill on the part of the operator, is all that is required to obtain correct results. No further treatment of the sample in a laboratory is necessary.

Graphical Analysis of Combustion Losses

By H. M. HOLADAY Chemist
Central Illinois Public Service Company

COMBUSTION data in a coal fired steam boiler plant are often analyzed into seven or more items of "losses" for the purpose of accounting for the total heat input to the furnace. These losses, when added to the heat accounted for in the steam output of the boiler, complete the so-called heat balance, and the information thus revealed is of the utmost value to the engineer who uses his operating data scientifically to maintain maximum efficiency.

However, there are many good engineers to whom the complete analysis of combustion data seems impractical because of the apparently complicated and difficult calculations. This is especially true in many smaller plants where the chief engineer does not have a specialized assistant for combustion control. Where it is necessary to combine combustion efficiency work with other supervisory duties it is not possible to do it in such detail as may be desirable in a larger organization. In such cases, graphical methods will give adequate results for the purpose of routine supervision.

Classification of Losses

The following classification includes the items usually deemed necessary for a fairly complete analysis of combustion losses.

A. Heat lost in flue gases, due to:

1. Moisture in the coal.
2. Hydrogen in the combustible.
3. Temperature of flue gases, above that of combustion air.
4. Air in excess of that theoretically required for complete combustion.
5. Incomplete combustion, as indicated by the presence of carbon monoxide in the flue gases.
6. Humidity of the combustion air supply.

B. Heat lost in refuse, due to:

1. Combustible matter in the refuse.
2. Temperature of the refuse above that of the coal entering the furnace.

C. Miscellaneous losses, usually unaccounted for, due to:

1. Radiation.
2. Combustible matter in the fly ash or smoke.
3. Blow-down losses, including blow-down valve leakage.
4. Steam leakage.

Data Required for Calculation of Losses

All of the flue gas and refuse losses can be accounted for by calculation from the following items of preliminary data.

1. Ultimate analysis of the coal.
2. Orsat analysis of the flue gases.
3. Flue gas temperature.
4. Combustible content of dry refuse.
5. Temperature of refuse.
6. Wet and dry bulb temperatures of combustion air.

Of the miscellaneous losses, radiation, smoke and steam leakage, cannot be estimated directly. Occasionally, it may be possible to check the blow-down losses, with certain arrangements of the system. In a continuous blow-down system, with a meter and thermometer on the discharge, this loss can be either accounted for, or shown to be nil. With intermittent blow-down, the loss cannot be measured unless some calibration can be made by means of an accessible tank or sump in the blow-down line.

The following figures represent the conditions considered in the examples worked out in subsequent paragraphs to illustrate each class of heat loss.

1. Ultimate analysis of coal.

		Dry Per cent	As Received (13.5 per cent moisture)
Carbon	C	74.0	64.0
Hydrogen	H	4.6	5.5
Oxygen	O	9.2	20.0
Nitrogen	N	1.2	1.0
Sulphur	S	1.2	1.0
Ash	A	9.8	8.5
Heating value, Btu per lb		12950	11200

2. Flue gas analysis.

   Carbon dioxide, CO_2 13.3 per cent; Oxygen, O_2 6.2 per cent; Carbon monoxide, CO 0.4 per cent.

3. Flue gas temperature, 310 F.

4. Combustible content of dry refuse, 13.5 per cent.

5. Temperature of refuse, 1700 F.

6. Temperature of combustion air, 88 F dry bulb; 79 F wet bulb.

Major Losses

MOISTURE—During the combustion of the coal, all of the moisture is evaporated and superheated, thereby absorbing some heat which is not recovered in the boiler before the gases escape to the stack. Besides the latent heat of vaporization, a certain amount of sensible heat is lost depending on the temperature of the exit gases. Letting H_m represent the heat content of the superheated water vapor, in Btu per pound, M the moisture

content and t the initial temperature of the coal, then the loss, L_m, is indicated by the following formula:

$$L_m = M(H_m - t + 32) \qquad (1)$$

From a table of the properties of superheated steam, or from Fig. 1, the heat content of the water vapor, H_m, may be determined. For example, at 310 F, $H_m = 1198$ Btu per pound. With 13.5 per cent moisture in the coal, at an initial temperature of 88 F, the loss would be:

$$L_m = 0.135\,(1198 - 88 + 32)$$
$$= 154 \text{ Btu per lb of coal.}$$

HYDROGEN IN COMBUSTIBLE MATTER—The combustion of hydrogen in the volatile constituents of the coal results in the formation of water vapor in addition to the moisture initially present in the fuel. The unrecovered heat from this source may be calculated in a way similar to the use of formula (1). Since each pound of hydrogen is equivalent to nine pounds of water, the weight of water formed from the hydrogen, H, in each pound of coal is equal to nine times the hydrogen content. The loss, L_H, which includes that due to the original moisture in the coal, may be expressed as follows:

$$L_H = 9H(H_m - t + 32) \qquad (2)$$

With 5.5 per cent total hydrogen in the coal,

$$L_H = 9 \times 0.055 \times 1142$$
$$= 565 \text{ Btu per lb coal.}$$

The loss, L_h, due to the hydrogen in the combustible only, would be the difference between 565 and 154, or 411 Btu per pound of coal. A formula for calculating this figure directly may be derived by a combination of formulas (1) and (2). Thus,

$$L_h = (9H - M)\,(H_m - t + 32) \qquad (3)$$

TEMPERATURE OF FLUE GASES, AND EXCESS AIR—The constituents of the dry flue gases may be calculated on the basis of either weight or volume, from the elementary chemical equations representing the combustion reactions. Thus,

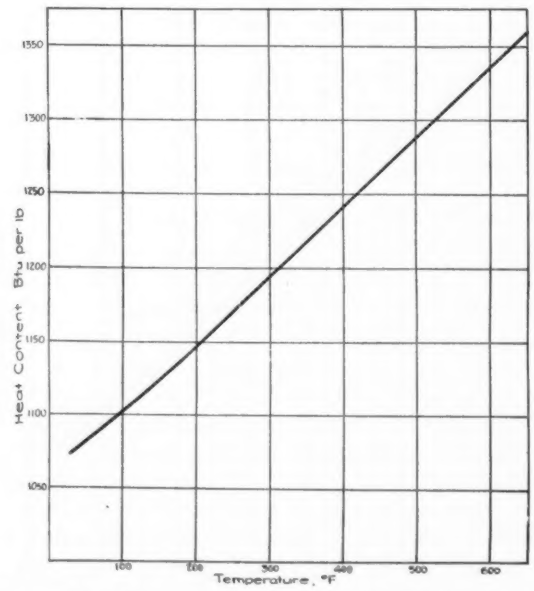


Fig. 1—Total heat content of superheated water vapor in the flue gas

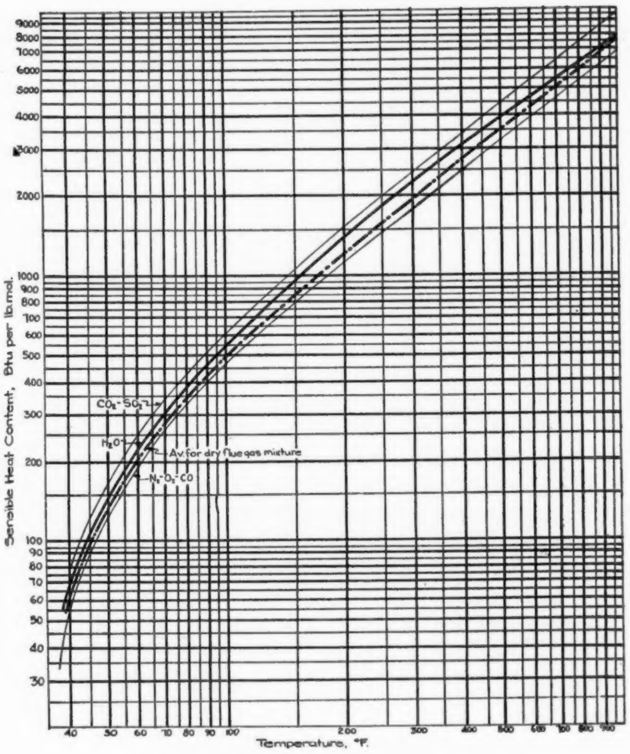


Fig. 2—Sensible heat content of gases

(From "Principles of Chemical Engineering" by Walker, Lewis and McAdams)

(a) $C + O_2 = CO_2$
(b) $2H_2 + O_2 = 2H_2O$
(c) $S + O_2 = SO_2$

Since the coal analysis is expressed in terms of weight, and the flue gas analysis in terms of volume, it is convenient to make use of another term, expressing in molecular proportions both volume and weight, for calculations involving both fuel and the products of combustion. This term is the "mol,"[1] which is the weight in pounds equivalent to 359 cu ft of a substance in the gaseous state at standard conditions. Equivalent weights and volumes on this basis are indicated in Table I.

It is an interesting fact that, while the specific heats, in Btu per pound, for various gases vary greatly, yet when expressed in terms of Btu per mol they are remarkably uniform. Fig. 2 shows the relatively constant rate of increase in heat content for the various gases involved in combustion calculations. In order to simplify these calculations the curve indicated by the broken line in Fig. 2 may be assumed to represent the average sensible heat content per mol for the flue gas.

With this information, all that remains is to determine the number of mols of gas produced by one pound of coal. This is relatively easy for theoretically complete combustion without excess air, making use of the figures in Table I which shows the fraction of a mol equivalent to one pound of each combustible constituent in the coal.

Reaction (a) shows that one mol of carbon reacts with one mol of oxygen, thereby producing one mol of carbon dioxide. One pound of carbon would therefore produce one-twelfth or 0.083 mol of carbon dioxide. Likewise, if one pound of coal contains 64.0 per cent of carbon it

[1] *Marks' Mechanical Engineers' Handbook* defines the mol as follows: "The mol is frequently taken as the unit of weight for gases. The mol is defined as m lb where m denotes the molecular weight; thus for oxygen 1 mol = 32 lb. For any gas, therefore, the volume of 1 mol at 32 F and atmospheric pressure is 358.65 cu ft.

will require 64.0 per cent of 0.083 mol, or 0.053 mol of oxygen and will produce 0.053 mol of carbon dioxide. Letting C represent the carbon content of the coal in a general formula, the oxygen required and the carbon dioxide produced on account of this constituent will be represented by the expression 0.083 C.

Letting H_s and H'_s represent these values, which may be determined from Fig. 2, the loss, L_s, due to sensible heat not recovered from the dry flue gases, is expressed as:

$$L_s = (H'_s - H_s) \quad \{(0.083\ \mathrm{C} + 0.031\ \mathrm{S}) + [3.78\,(1 + E) + E]\,(0.083\ \mathrm{C} + 0.031\ \mathrm{S} + 0.25\ \mathrm{H} - 0.031\ \mathrm{O})\} \tag{7}$$

TABLE I—EQUIVALENT WEIGHTS AND VOLUMES

	Carbon, C			Sulphur, S			Hydrogen, H_2			Oxygen, O_2			Carbon dioxide, CO_2	
Lb	Cu Ft	Mols	Lb	Cu Ft	Mols	Lb	Cu Ft	Mols	Lb	Cu Ft	Mols	Lb	Cu Ft	Mols
12	359	1	32	359	1	2	359	1	32	359	1	44	359	1
1	29.9	0.083	1	11.2	0.031	1	179.5	0.50	1	11.2	0.031	1	8.2	0.023

Since the carbon dioxide determination in the Orsat analysis includes sulphur dioxide also, the total volume determined as carbon dioxide in the flue gases from one pound of coal will be 0.083 C + 0.031 S. This would represent the total volume of gas produced, except moisture, if the combustion had taken place in pure oxygen. But in air, the oxygen is diluted by 3.78 times its volume of nitrogen. Referring to reactions (*a*), (*b*) and (*c*) again, it is observed that one mol of either carbon or sulphur requires one mol of oxygen plus 3.78 mols of nitrogen, when burning in air. However, one mol of hydrogen requires only 0.5 mol of oxygen. The total volume of nitrogen left from the air used for combustion may therefore be represented as 3.78 (0.083 C + 0.031 S + 0.250 H). Since coal always contains a certain amount of oxygen, the amount required from the air is reduced accordingly. The expression for nitrogen in the flue gas, corrected for the oxygen content of the coal, would thus be

$$3.78\,(0.083\ \mathrm{C} + 0.031\ \mathrm{S} + 0.250\ \mathrm{H} - 0.031\ \mathrm{O})$$

The theoretical volume of dry flue gas mixture is the sum of this nitrogen and the carbon dioxide, or

$$0.083\ \mathrm{C} + 0.031\ \mathrm{S} + 3.78\,(0.083\ \mathrm{C} + 0.031\ \mathrm{S} + 0.25\ \mathrm{H} - 0.031\ \mathrm{O}) = 4.78\,(0.083\ \mathrm{C} + 0.031\ \mathrm{S}) + 3.78\,(0.25\ \mathrm{H} - 0.031\ \mathrm{O})$$

The actual volume of dry flue gas is always greater than this because some excess air is necessary to secure complete combustion. Letting E represent the proportion of excess air, the actual amount of dry flue gas, in mols per pound of coal, is expressed as follows:

$$\underbrace{(0.083\ \mathrm{C} + 0.031\ \mathrm{S})}_{\text{carbon dioxide}} + \underbrace{E\,(0.083\ \mathrm{C} + 0.031\ \mathrm{S} + 0.25\ \mathrm{H} - 0.031\ \mathrm{O})}_{\text{oxygen}} + \underbrace{3.78\,(1 + E)\,(0.083\ \mathrm{C} + 0.031\ \mathrm{S} + 0.25\ \mathrm{H} - 0.031\ \mathrm{O})}_{\text{nitrogen}} \tag{4}$$

This expression separates the mixture into the components as determined by an Orsat analysis. The same expression may be rearranged to indicate all of the excess air separately. Thus,

$$\underbrace{(0.083\ \mathrm{C} + 0.031\ \mathrm{S})}_{\text{carbon dioxide}} + \underbrace{3.78\,(0.083\ \mathrm{C} + 0.031\ \mathrm{S} + 0.25\ \mathrm{H} - 0.031\mathrm{O})}_{\text{residual nitrogen from the theoretical air supply}} + \underbrace{4.78\,E\,(0.083\ \mathrm{C} + 0.031\ \mathrm{S} + 0.25\ \mathrm{H} - 0.031\ \mathrm{O})}_{\text{excess air}} \tag{5}$$

Simplified, either (4) or (5) may be written as follows:

$$(0.083\ \mathrm{C} + 0.031\ \mathrm{S}) + [3.78\,(1 + E) + E]\,(0.083\ \mathrm{C} + 0.031\ \mathrm{S} + 0.25\ \mathrm{H} - 0.031\ \mathrm{O}) \tag{6}$$

As previously indicated, this expression represents the number of mols of dry flue gas mixture produced by the combustion of one pound of coal. With this determined, the heat loss can be figured by multiplying the number of mols by the increase in heat content from the combustion air temperature to the exit temperature.

Since excess air is not determined directly, but must be calculated from the results of an Orsat analysis, an expression for E in terms of CO_2 must be derived, so that the value of E may be substituted in formula (7). It is evident from expressions (4), (5) and (6) that the CO_2 content, that is, the ratio of carbon dioxide to the total volume of dry flue gases, may be written as follows:

$$CO_2 = \frac{0.083\ \mathrm{C} + 0.031\ \mathrm{S}}{0.083\ \mathrm{C} + 0.031\ \mathrm{S} + [3.78\,(1 + E) + E]\,(0.083\ \mathrm{C} + 0.031\ \mathrm{S} + 0.25\ \mathrm{H} - 0.031\ \mathrm{O})} \tag{8}$$

From formula (8), E may be expressed in terms of CO_2.

$$E = \frac{(0.083\ \mathrm{C} + 0.031\ \mathrm{S})\,(1 - CO_2)}{4.78\,CO_2\,(0.083\ \mathrm{C} + 0.031\ \mathrm{S} + 0.25\ \mathrm{H} - 0.031\ \mathrm{O})} - 0.79 \tag{9}$$

In order to avoid dealing with extremely small decima fractions, formula (9) may be rewritten using, instead of mols, values for equivalent cubic feet per pound, as indicated in Table I. Then,

$$E = \frac{(29.9\ \mathrm{C} + 11.2\ \mathrm{S})\,(1 - CO_2)}{4.78\,CO_2\,(29.9\ \mathrm{C} + 11.2\ \mathrm{S} + 89.8\ \mathrm{H} - 11.2\ \mathrm{O})} - 0.79 \tag{10}$$

Substituting the assumed value of 0.133 or 13.3 per cent CO_2 in formula (10), and using figures from the

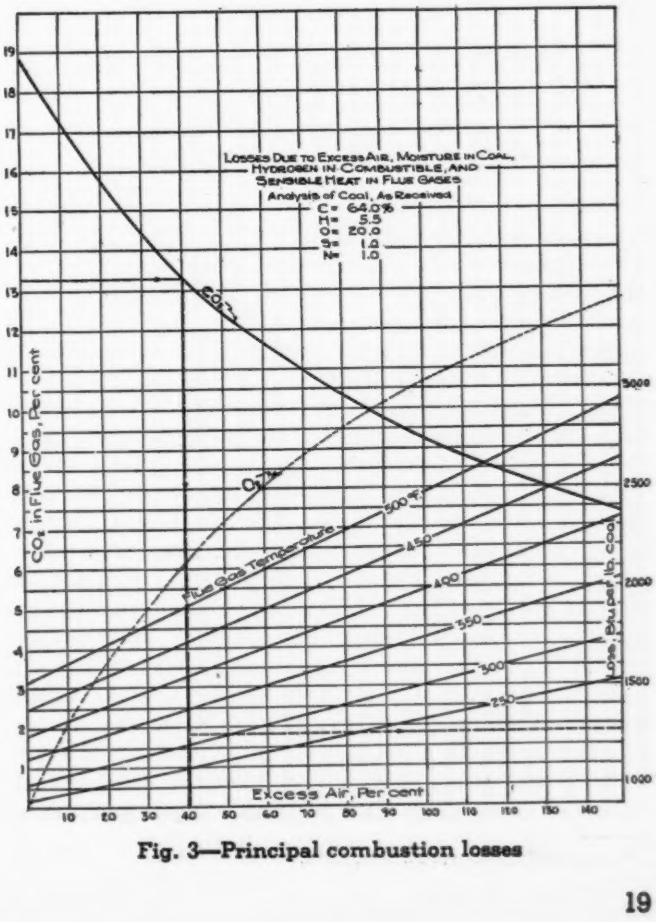


Fig. 3—Principal combustion losses

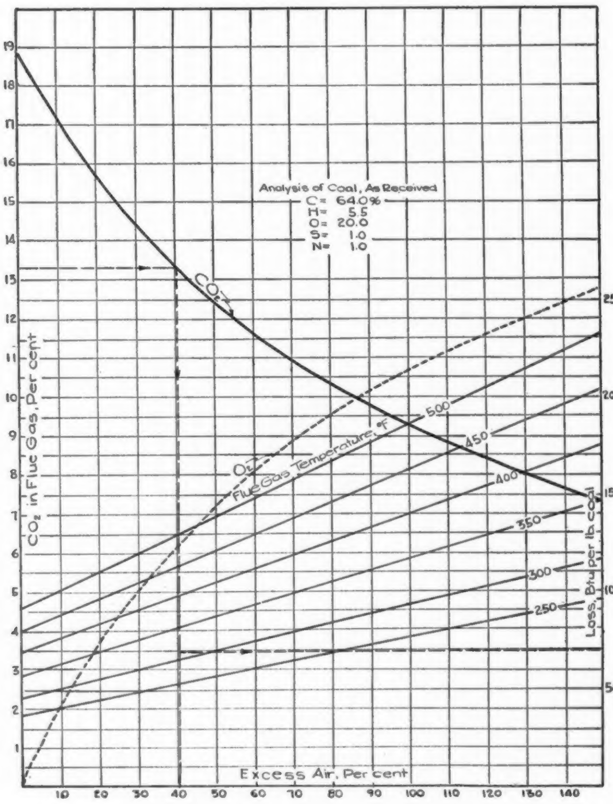


Fig. 4—Heat loss in dry flue gas

assumed coal analysis previously stated, it is found that $E = 40.5$ per cent.

Substituting this, in turn, in formula (7), and finding H_s and H'_s from Fig. 2 with the combustion air temperature at 88 F and the exit temperature at 310 F, the loss is:

$$L_s = (2000 - 405)\ [0.053 + (3.78 \times 1.405 + 0.405)\ 0.061]$$
$$1595 \times 0.403$$
643 Btu per lb coal.

Graphical Determination of Major Losses

Many forms of graphical expression may be used to represent the losses calculated by the foregoing method. The alignment chart[2] is convenient to use when constructed with properly selected scales. It has some limitations, however, and the conventional chart with rectilinear co-ordinates is, on the whole, more easily constructed and more usable for the average engineer. Fig. 3 illustrates a convenient form. The CO_2 curve will vary slightly in form and position, depending on variations in the coal analysis. However, rather extreme variations in the analysis are necessary to produce very much of a shift in the curve. For this reason, a single curve, when once constructed on the basis of a representative analysis, will serve all practical purposes so long as a very radical change is not made in the coal supply. For example, with the specimen analysis used for Fig. 3, a carbon dioxide content of 13.3 per cent in the flue gas indicates 40.5 per cent excess air. A carbon content of 74.0 per cent instead of 64.0 per cent in the coal will make the chart 2.5 per cent too low. That is 13.3 per cent carbon dioxide should indicate 43.0 per cent excess air instead of 40.5 per cent. Hydrogen variations are more important in this respect. A decrease of 1 per cent in the hydrogen content, corrected for moisture, would make the chart 5.5 per cent low in excess air.

In Fig. 3, a series of lines is drawn to represent various flue gas temperatures. At the point where the temperature line intersects the co-ordinate corresponding to the excess air, the total losses due to moisture, hydrogen, excess air and flue gas temperature, are found on the right-hand vertical scale. In the example discussed, the sum of these losses is 1210 Btu per pound of coal. This is somewhat less than the figure shown on the chart, because an assumed value of 70 F instead of 88 F for the initial temperature of the combustion air was used in preparing the chart. The calculated loss for 70 F initial temperature is 1270 Btu, a discrepancy of 60 Btu or 5 per cent for 18 deg initial temperature difference.

Separate Charts for Moisture, Hydrogen and Dry Flue Gas Losses—If the moisture content is likely to change very radically, it may be found advisable to modify Fig. 3 so as to indicate only losses in the dry flue gases. This would simply shift the position of the right-hand vertical scale as shown by Fig. 4. Another chart, Fig. 5, shows separately the moisture losses.

Minor Losses

Loss Due to Incomplete Combustion—The occurrence of carbon monoxide in the flue gas indicates that something is radically wrong with combustion conditions. It is seldom found in the normal operation of boilers with adequate combustion supervision. Even a small carbon monoxide content may indicate an appreciable heat loss, because the amount of heat developed in the formation of carbon monoxide is much less than that generated by complete combustion to carbon dioxide. The following reactions indicate this:

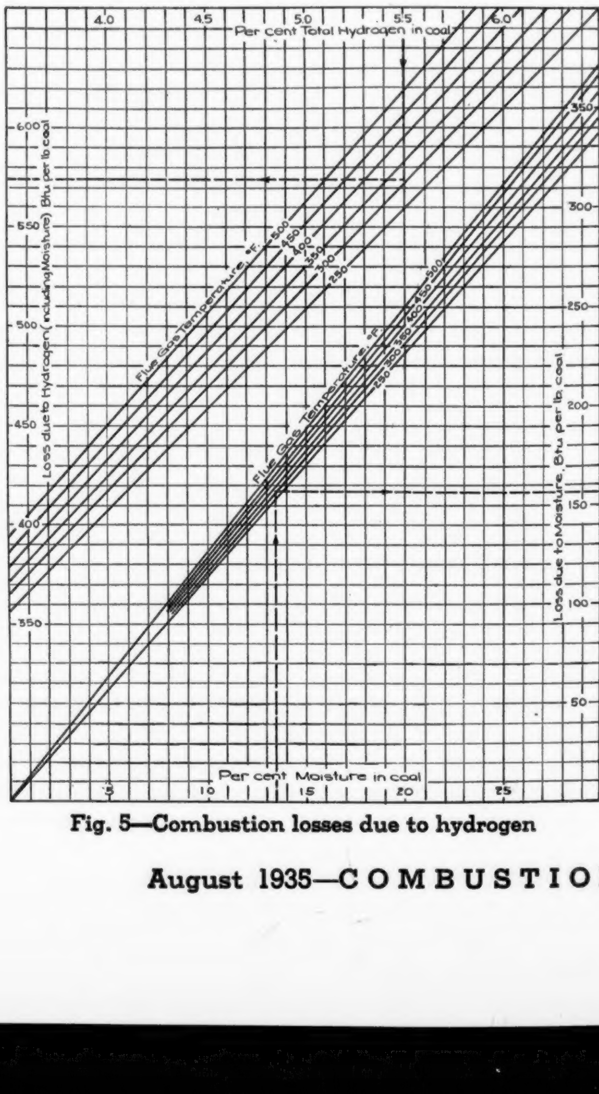


Fig. 5—Combustion losses due to hydrogen

[2] Ice and Refrigeration, Feb. 1935, p. 134.

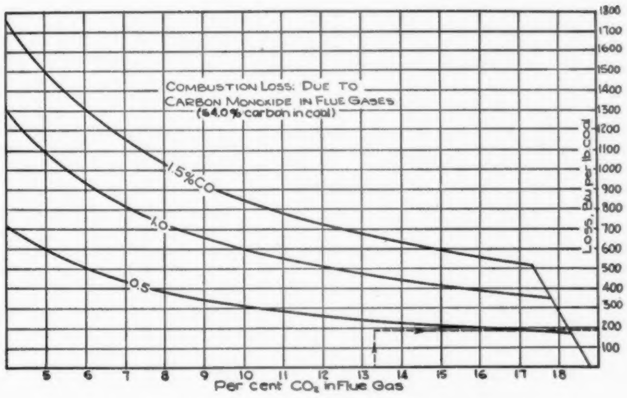


Fig. 6—Per cent CO_2 in flue gas

$$2\ C + O_2 = 2\ CO\ \ (\ 4380\ \text{Btu per lb carbon})$$
$$2\ C + 2O_2 = 2\ CO_2\ (14540\ \text{Btu per lb carbon})$$

Thus, for every pound of carbon burned to carbon monoxide instead of to carbon dioxide, the loss is the difference between 14,540 and 4380 Btu, or 10,160 Btu. The ratio, $\frac{CO}{Co_2 + CO}$, indicates the proportion of the total carbon which has been burned to carbon monoxide. Then $\frac{10{,}160\ CO}{CO_2 + CO}$ expresses the number of Btu lost per pound of carbon. Letting C represent the carbon content of the coal, the loss, L_{co}, may be determined in Btu per pound of coal, by the following general formula.

$$L_{co} = \frac{10{,}160 \times C \times CO}{CO_2 + CO} \tag{11}$$

Substituting values previously stated for illustration.

$$L_{co} = \frac{10.160 \times 0.64 \times 0.004}{0.133 + 0.004}$$
$$= 190\ \text{Btu per lb coal.}$$

A chart, like Fig. 6, covering a relatively wide range of conditions can be constructed easily to show at a glance any loss due to the formation of carbon monoxide.

Humidity of Combustion Air Supply—Except under rather extreme conditions, or when a very detailed analysis of losses is to be made, the heat carried away by the water vapor initially in the combustion air is an insignificant quantity and may be included with other items of unaccounted for loss. However, if the wet and dry bulb temperatures are read, it is not difficult to calculate the loss. It is first necessary to determine the weight of air, W, used for combustion. A review of expression (4) indicates a convenient method of figuring this value. The weight of one mol of oxygen being 32 lb, and air being 4.35 times the weight of its oxygen, the following formula may be written:

$$W = 4.35 \times 32\ (0.083\ C + 0.031\ S + 0.25\ H - 0.031\ O)\ (1 + E)$$
$$= (11.5\ C + 4.35\ S + 34.6\ H - 4.3\ O)\ (1 + E) \tag{12}$$

From a psychrometric chart or table, the amount of moisture in the air can be determined by the wet and dry bulb temperature readings. The moisture, M, is usually indicated in terms of grains per pound of dry air. Referring back to Fig. 1 for the heat content, H_m and H_m', at the initial and exit temperatures, the loss L_w, may be written as follows:

$$L_w = \frac{W\ M\ (H_m' - H_m)}{7000} \tag{13}$$

Substituting in formula (12) figures from the specimen coal analysis, and assuming 40.5 per cent excess air,

$$W = (7.36 + 0.04 + 1.90 - 0.86)\ 1.405$$
$$= 8.44 \times 1.405$$
$$= 11.86\ \text{lb air per lb coal.}$$

If the temperature of the combustion air is 88 F, dry bulb, and 79 F, wet bulb, the humidity is 134 gr per lb of dry air. Assuming an exit temperature of 310 F, for determining H_m', the loss is figured as follows:

$$L_w = \frac{11.86 \times 134\ (1198 - 1097)}{7000}$$
$$= 23\ \text{Btu per lb coal.}$$

In this case, the loss due to humidity is negligible for practical purposes. Where it is found to be sufficient to justify routine determination, a chart may be prepared to cover the necessary range of conditions. A convenient form of such a chart is shown in Fig. 7. This chart was prepared on the basis of an assumed initial air temperature of 70 F.

Combustible Matter in Refuse—The ash and clinker discharged from the furnace always contain an appreciable amount of unburned carbon. This results in a loss which may perhaps be reduced, but cannot be entirely eliminated without incurring, below the optimum, a still greater loss in other ways, mainly by increasing excess air.

The amount of refuse combustible per pound of coal is equal to the combustible content of the refuse times the amount of refuse per pound of coal. Letting A represent the ash content of the coal, and C_a, the combustible content of the refuse, then C_c, the refuse combustible per pound of coal, may be expressed as follows:

$$C_c = C_a \frac{A}{1 = C_a} \tag{14}$$

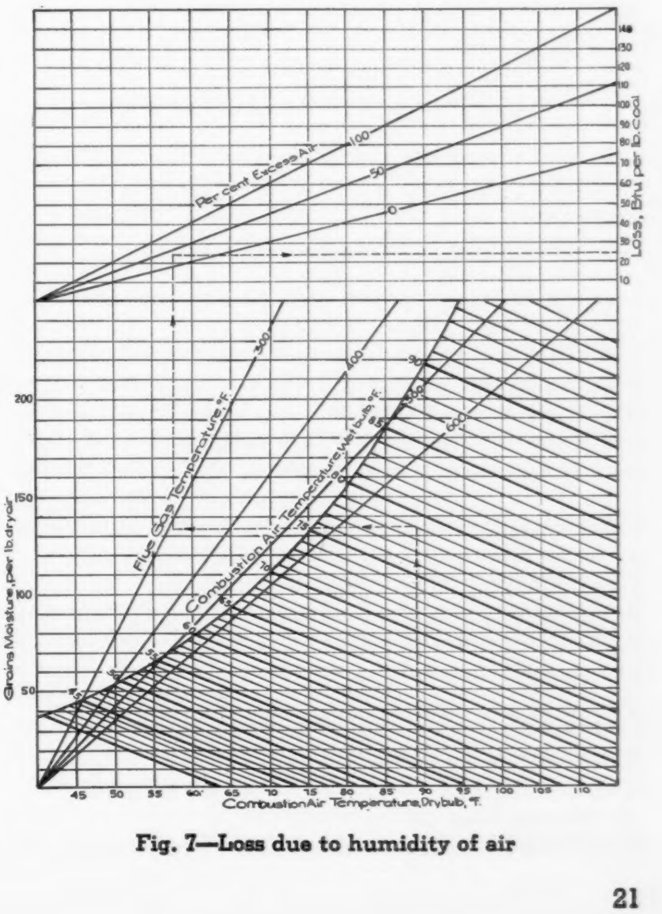


Fig. 7—Loss due to humidity of air

For extreme accuracy it would be necessary to measure the actual heating value of the refuse in order to determine the amount of heat loss. However, for ordinary purposes it is preferable to assume that all of the combustible in the refuse is carbon with a heating value of approximately 14,540 Btu per pound. The loss, L_c, may then be shown by the following formula:

$$L_c = \frac{14{,}540\, C_a A}{1 - C_a} \qquad (15)$$

With an ash content of 8.5 per cent in the coal, and 13.5 per cent combustible matter in the refuse, the loss is:

$$L_c = \frac{14{,}540 \times 0.135 \times 0.085}{0.865}$$
$$= 193 \text{ Btu per lb coal.}$$

A chart may be prepared to cover the normal range of conditions in any plant, and the loss thus shown graphically, as in Fig. 8.

Temperature of Refuse—The heat content of the refuse is usually a negligible loss, and since it is difficult to measure accurately, this item is often included in the unaccounted for losses.

The weight of refuse per pound of coal is equal to the ash content of the coal plus the combustible refuse, or $\frac{A}{1 = C_a}$. This quantity, multiplied by the specific

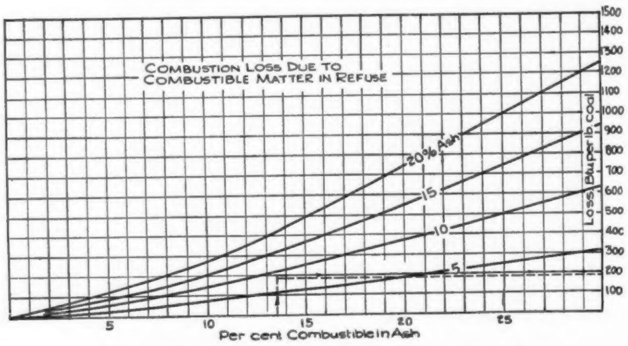


Fig. 8—Loss due to combustible in refuse

heat, s, of the refuse and also by the difference between the discharge temperature, t', of the refuse, and the initial temperature, t, of the coal, determines the amount of heat lost. This loss, L_a, may be expressed as

$$L_a = \frac{As(t' - t)}{1 - C_a} \qquad (16)$$

It will not usually be considered worth while to determine the specific heat of the refuse. An assumed value of 0.2 may be used for this item. The refuse temperature should be measured with a pyrometer as it is discharged from the furnace. If it is found that the discharge temperature is too low for measurement with an optical pyrometer, the loss may be neglected.

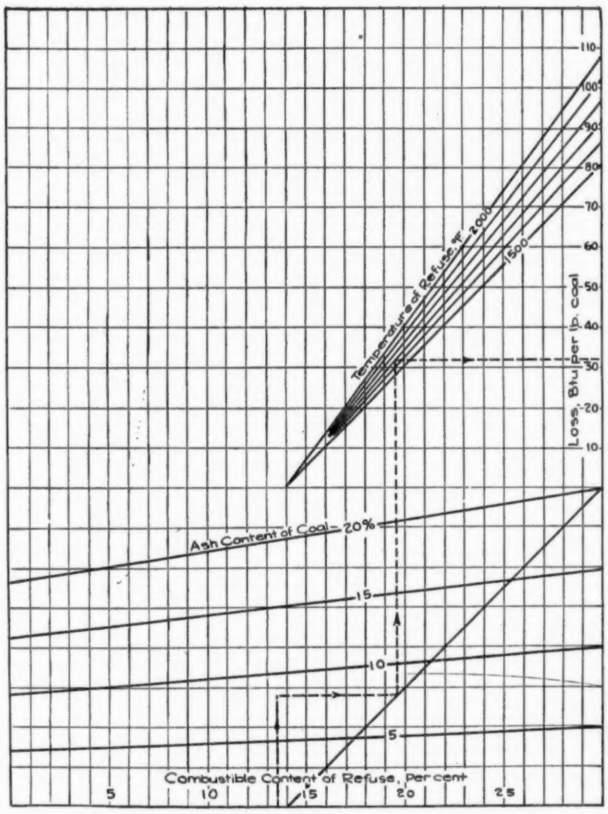


Fig. 9—Loss from sensible heat in refuse

With 8.5 per cent ash in the coal, 13.5 per cent combustible in the refuse, 88 F initial temperature of the coal, and 1700 F discharge temperature of the refuse, the loss is found as follows:

$$L_a = \frac{0.085 \times 0.2\,(1700 - 88)}{1 - 0.135}$$
$$= 32 \text{ Btu per lb coal.}$$

A chart similar to Fig. 9 may be prepared for routine estimates of this loss.

The Heat Balance

A typical heat balance is shown in Table II. Item 1 is determined by measuring the output of the boiler. Items 2 to 8, inclusive, cover the various losses analyzed in the foregoing discussion and are determined either graphically or by calculation. For convenient reference, a formula is given for the calculation of each item of loss, and in another column the corresponding chart for graphical solution of the problem is indicated. Item 9, of course, is determined by subtracting the sum of items 1 to 8, inclusive, from item 10.

TABLE II—TYPICAL HEAT BALANCE

	Item	Formula	Chart	Btu per lb coal	Per cent
1	Heat absorbed by boiler			9216	82.3
	Flue gas losses:				
2	Moisture in coal	(1) $L_m = M(H_m - t + 32)$	Fig. 5	154	1.4
3	Hydrogen in combustible	(3) $L_h = (9H - M)\,(H_m - t + 32)$	Fig. 5	413	3.7
4	Sensible heat in dry gases and excess air	(7) $L_s = (H'_s - H_s)\,\{(0.083\,C + 0.031\,S) + [3.78\,(1 + E) + E]\,(0.083\,C + 0.032\,S + 0.25\,H - 0.031)\}$	Fig. 4	643	5.7
5	Incomplete combustion	(11) $L_{co} = \frac{10160 \times C \times CO}{CO_2 + CO}$	Fig. 6	190	1.7
6	Humidity of combustion air supply	(13) $L_w = \frac{WM(H'_m - H_m)}{7000}$	Fig. 7	23	0.2
	Refuse losses:				
7	Combustible matter in refuse	(15) $L_c = \frac{14540\, C_a A}{1 - C_a}$	Fig. 8	193	1.7
8	Sensible heat in refuse	(16) $L_a = \frac{As(t' - t)}{1 - C_a}$	Fig. 9	32	0.3
9	Losses unaccounted for			336	3.0
10	Heating value of coal			11200	100.0

Pressure Distribution in a Long-Throat Steam Nozzle

Investigations conducted at Pennsylvania State College showed that with a nozzle of this type there is no drop in pressure below the critical within the nozzle; also, if a high discharge coefficient be used, the discharge should be based on the pressure drop to some intermediate pressure near the beginning of the throat rather than the pressure at the end of the throat.

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A STUDY of the pressure drop through a long throat nozzle with a view to determining how accurately such a device can serve as an improvised flow meter was recently made in the mechanical engineering laboratory at Pennsylvania State College. Fig. 1 shows the arrangement of apparatus. A rounded entrance nozzle, six inches long, with an 0.749 in. throat diameter and $5^5/_8$ in. throat length, was equipped with a search tube of 0.407 in. diameter for measuring the static pressure at any point along the axis. This search tube was carefully aligned on brackets placed inside the expansion chambers on each end of the nozzle. These large chambers reduced entrance and exhaust velocities.

The position of the search tube was indicated on the scale at the right. Three small pressure holes, all in the same radial plane, were made in the tube. The important fact to note is that the search tube was closed at the left-hand (high-pressure) end and the holes for determining pressure were placed not near the end but far enough back so that the tube would still extend throughout the entire length of the nozzle even when the tube was drawn back to read the pressure at the exhaust end.

All piping was well insulated to minimize heat losses.

Fig. 2 is a plot of the pressures as determined at various points along the nozzle. The abscissa shows the position along the nozzle where the pressures were determined. To the left of the zero position is naturally the chamber before the nozzle; the zero position indicates the beginning of the nozzle; $^3/_8$ in. the beginning of the long throat; and 6 in. the end of the throat.

Nine complete runs were made, five with the back pressure less than the critical pressure and four with the back pressure greater then the critical pressure. In the case of the former, it was found that the critical pressure was not reached until the very end of the throat; and in the latter case, the back pressure was not reached until the end of the throat. This is to be expected, as the long throat will cause a wire drawing effect. Runs were made with the initial condition of the steam practically dry, or slightly superheated, the critical pressure being always in the wet saturated region.

The actual quantity flowing was measured by condensing and weighing the steam. The theoretical flow was computed by the continuity of mass equation,

$$w = \frac{\text{area} \times \text{velocity}}{\text{specific volume}}.$$

The area used was that of the annular space between the nozzle and the tube.

The velocity was computed on the basis of an isentropic heat drop from the well known equation,

$$\text{velocity} = 223.8 \sqrt{h_1 - h_2}.$$

The symbol h_1 refers to the heat content of the high-pressure steam (determined by calorimeter) and h_2 is the heat content at the pressure existing at the point where the velocity is computed.

The coefficient of discharge was then computed as the ratio of the actual flow to the theoretical. These coefficients computed in accordance with the pressures noted at distances of $^3/_8$, 1, 2, 3, 4, 5 and 6 in. are shown in the plot of Fig. 3. It is seen that the least dispersion of coefficients occurs at a position two inches along the nozzle. A good general value at this point would be 0.84. This can be used with reasonable accuracy regardless of whether the back pressure is greater or less than critical. It will be noted that, in general, the coefficients at other points have a tendency to run higher for the runs made with back pressures less than critical than for the other runs. However, if a gage be placed at the two-inch position, it is seen that the flow computed therefrom could be corrected with the coefficient 0.84 regardless of the back pressure.

The data here presented checked data previously determined on a similar type of nozzle having a diameter of 0.25 in. This had been tested without a search tube, pressures being determined by gages attached rigidly to the apparatus. It is seen that for a nozzle of this type having a high ratio of length of throat to diameter of throat, if a high discharge coefficient is to be used, the discharge should be based on the pressure drop to some intermediate pressure near the beginning of the throat, rather than the pressure at the end of the throat. Furthermore, the small pressure drop which will then be obtained can be determined accurately by a differential

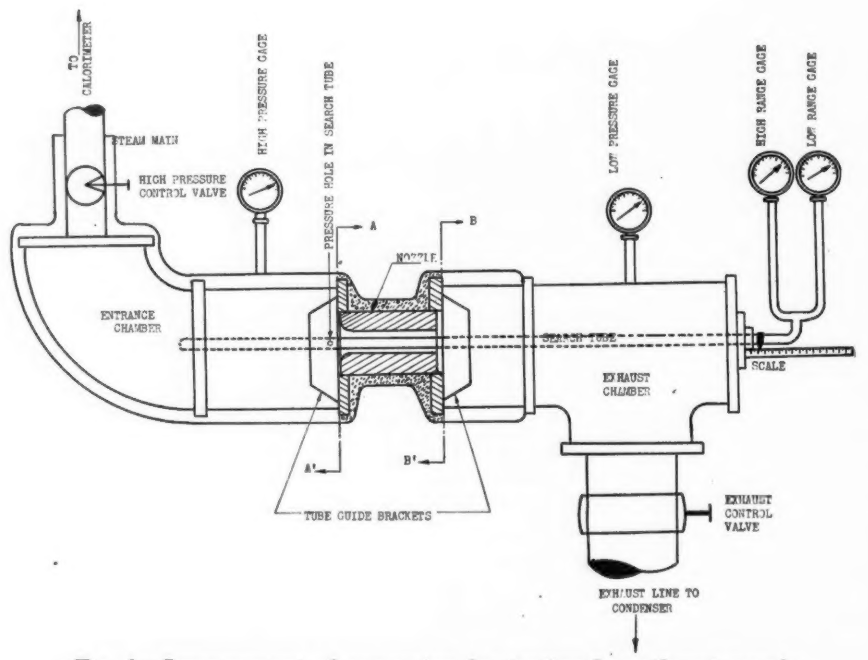

Fig. 1—Arrangement of apparatus for testing long-throat nozzle

gage, thus eliminating the possible error due to a difference between spring gage readings.

On the plots, runs numbered 2, 5, 6, 7 and 10 were made with the back pressure less than the critical pressure, and the remaining runs had the back pressure greater than the critical, with the exception of run number 8, for which the back pressure was held at the critical value, and whose pressures practically duplicate those of run number 7, as shown in Fig. 2.

It is seen that with a nozzle of this type, there is no drop in pressure below the critical within the nozzle. Also, for all the runs made, the time required for the steam to pass through the nozzle is extremely short—less than 1/1000 of a second. Obviously, then, with superheated steam expanding into the wet vapor region, supersaturation will occur, and recovery from supersaturation will not take place until after the steam leaves the nozzle. For the set of initial conditions used in the test runs, however, the quality of the steam at the critical pressure was always high, over 96 per cent, so that computations based on supersaturated flow (using $PV^{1.3} = \text{const.}$) do not differ widely from those based on isoentropic conditions. Furthermore, if flow is based on conditions at the two-inch position, the quality is still higher than at the critical pressure, so that the discrepancy between the two methods becomes very small, the discharge coefficient in general running slightly lower when flow is computed according to supersaturated conditions. For example, take run number 2; the coefficient under isoentropic condition is 0.875, and under supersaturated conditions, 0.866. For the 6-in. position, the coefficient under isoentropic conditions is 0.838, and under supersaturated conditions is 0.816. For this run, the steam had an initial superheat of 7 degrees. Where the initial superheat is higher, as for example in run number 5, where it is 36 degrees, the correlation is still better, as the coefficients at the 2-in. position are, respectively, 0.850 and 0.842. As the supersaturated flow method is somewhat more laborious than the simple isoentropic flow method, it can be concluded that the latter can be used with good accuracy in flow meter work.

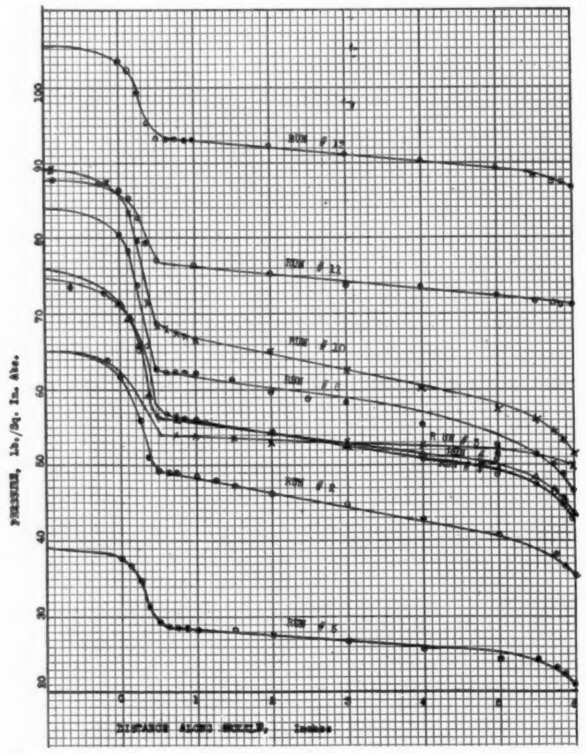

Fig. 2—Pressures plotted against points along the nozzle

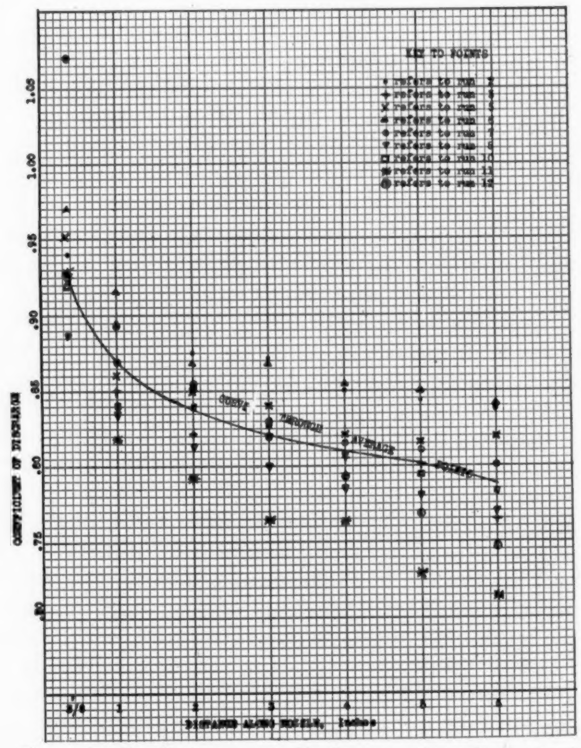

Fig. 3—Coefficients of discharge plotted against distance along nozzle

Influence of Time on Creep of Steels*

By

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Extended-time creep tests conducted at 1000 F on plain carbon steel and chromium-silicon-molybdenum steel, indicate that at least in two cases considered, the 500-hr test is a more conservative criterion than the 1000-hr test. The assumption ordinarily made that a creep rate of 0.10 per cent per 1000 hr represents a creep rate of 1.0 per cent per 10,000 hr is in consequence open to question, at least for some steels. Indications are that for the plain carbon steel this hypothesis may be approximately true but for the chromium-silicon-molybdenum steel this relationship was not found. In fact, the stress giving this creep rate at the end of 1000 hr produces, after 5000 hr, a creep rate of 1.0 per cent per 1000 hr.

IN DETERMINING the creep characteristics of metals at elevated temperatures, there has always been a question as to the length of time these tests should be conducted. The ideal procedure would be to maintain specimens under the desired operating stresses and temperatures for time periods equivalent to the commercial life desired. For the majority of cases, however, this is not possible as the erection of the apparatus could not be sufficiently delayed to permit completion of the creep tests. Moreover, if such a procedure were followed, the amount of available creep data would be extremely small and the laboratory phase of the work would consequently fall considerably behind commercial progress, thus making the selection of the proper metals for high-temperature service even more a matter of chance than at present.

Present-day creep tests are extended for periods ranging from a few hours to several thousand hours, with the vast majority probably falling within the range of 500 to 1000 hr. Irrespective, however, of the time involved in the tests, it is customary to report the results in terms of the stresses required for creep rates of 1 per cent in either 100,000 or 10,000 hr. These results are obtained on the assumption that a creep rate of 0.01 per cent per 1000 hr is equivalent to 1.0 per cent per 100,000 hr and 0.10 per cent per 1000 hr equivalent to 1.0 per cent per 10,000 hr. Certain groups are now advocating that the results be expressed in terms of either inches per inch per hour, or per cent per hour. This procedure has the advantage that, through extrapolation, the results can readily be expressed in any given units. The importance of the time factor is not eliminated, however, and the time period at which the rate is computed should be stated.

The purpose of this paper is to present data from creep tests which have been in progress for several thousand hours and to indicate how the creep characteristics may vary, depending upon the duration of the tests. Also, in order that the complete time-elongation characteristics might be obtained, certain of the stresses were purposely chosen of sufficient magnitude actually to cause rupture at certain periods during the progress of the tests.

Materials

Two steels were submitted to the extended-time creep tests, one of which was a plain carbon steel of the S.A.E. 1015 type and the other a low-alloyed chromium-silicon-molybdenum steel. Both were secured from The Timken Steel and Tube Co. and were melted in a commercial electric furnace. The material was heat-treated in the form of 1-in. round bars and the specimens were machined after the heat treatment. Information concerning their chemical composition, heat treatment, Brinell hardness and "inherent" grain size is given in Table I.

TABLE I—CHEMICAL COMPOSITION, HEAT TREATMENT, BRINELL HARDNESS AND GRAIN SIZE OF STEELS

Designation	Chemical Composition, Per Cent: Carbon	Manganese	Silicon	Chromium	Molybdenum	Heat Treatment	Brinell Hardness	Grain Size
S.A.E. 1015	0.15	0.50	0.23	..	..	Annealed at 1550 F	134	4 to 5
Cr-Si-Mo	0.07	0.42	0.72	1.25	0.54	Annealed at 1550 F	123	4 to 5

Both steels were tested in the same condition of heat treatment, the annealed, and both possessed the same "inherent" grain size. They differed slightly in their hardness with the carbon steel being somewhat the harder. Their chief difference, however, was in their chemical composition.

Test Procedure

The standard creep-testing apparatus of the University of Michigan, was used for these tests. The elongation or creep is measured by an optical extensometer system capable of reading to 0.0000028 in. per inch of 2-

* From a paper before the Thirty-eighth Annual Meeting of the American Society for Testing Materials, at Detroit, Mich., June 24–28, 1935.

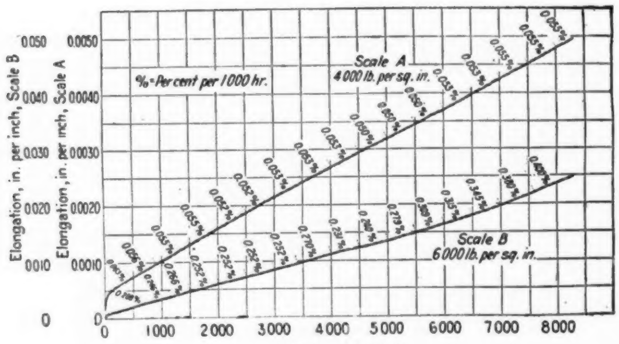


Fig. 1—Time-elongation curves at 1000 F for carbon steel (electric)

in. gage length. Standard 0.505-in. diameter specimens were used and the collars of the extensometer system were attached at both ends of the 2-in. gage section. All the testing details were in agreement with the A.S.T.M. Tentative Method of Test for Long-Time (Creep) High-Temperature Tension Tests of Metallic Materials (E 22–34 T).[1]

Five different stresses, ranging from 13,000 to 34,100 lb per sq in., were applied to the alloy steel and two, of 4000 and 6000 lb per sq in., to the plain carbon steel. Elongation readings were taken daily and the results plotted as time-elongation curves. The slopes (creep rate) of these curves were determined at approximately 500-hr intervals and the rates thus obtained plotted against the corresponding times. The creep rates, for the various times, were then plotted on logarithmic coordinates with the corresponding loads, and the stresses for definite creep rates (0.01, 0.10 and 1.0 per cent per 1000 hr) thus computed. In order to show the influence of time on the reported values, these creep values were then plotted against time.

To facilitate the reproduction of the various figures, the sensitivity of the scale of plotting has in certain cases been greatly reduced. This applies especially to the time-elongation and the time-rate of creep curves. All of the reported values, however, were obtained from the original, and not the reduced, scales.

Creep Test

Results are presented from creep tests at 1000 F on a plain carbon steel and on a chromium-silicon-molybdenum steel, both of which were in the annealed condition. Two stresses, of 4000 and 6000 lb per sq in., were considered in the case of the carbon steel and five, ranging from 13,000 to 34,100 lb per sq in., with the alloy steel. The tests on the plain carbon steel have now been in progress for approximately 8500 hr and those on alloy steel from 2000 to 8000 hr. The time-elongation curves obtained are given in Figs. 1 and 2. As stated previously, the sensitivity of the elongation scale has been greatly reduced in both figures to facilitate reproduction.

Time Versus Elongation

Fig. 1 gives the results obtained with the carbon steel. It is to be noted that the curve for the lower stress, 4000 lb per sq in., is plotted to a scale ten times as sensitive as that used for the larger stress. The rate of creep (slope) was determined for various time-intervals, which averaged about 500 hr, and the resulting rates, expressed in terms of per cent per 1000 hr, are indicated on the curves. Neither of these specimens has as yet fractured and the tests are still in progress.

Corresponding results for the alloy steel are given in Fig. 2. In this case certain of the stresses were purposely chosen of sufficient magnitude to cause fracture. This was done in order that the complete time-elongation curves would be obtained, thus showing the behavior of the material in the so-called third stage of creep (stage of increasing creep rate), as well as in the first and second stages. In order to produce this condition, however, the stresses necessarily were considerably greater than those which would ever be considered for commercial applications. It will be observed that with the stress of 34,100 lb per sq in., fracture was obtained in 2625 hr, with 30,000 lb per sq in. in 3250 hr, and with 24,600 lb per sq in. in 6151 hr. The remaining specimens have not failed and the tests are still being continued. With the stress of 17,500 lb per sq in., however, the time-elongation curve appears to be in the third stage, indicating that fracture may eventually occur.

Tests are now in progress on the carbon steel under stresses greater than 6000 lb per sq in. in order that the third-stage characteristics of this material, under different stresses, can be determined.

Time Versus Creep Rate

In order to show the influence of time on the resulting creep rates for the stresses considered, the slopes (creep rates) of the curves of Figs. 1 and 2 are plotted against time in Figs. 3 and 4. In these two figures the creep rates at the various designated times are defined as the rates which would have been reported had the tests been discontinued at that particular time. It should also be emphasized that the creep rates considered are those occurring in the so-called second stage and not for the entire test period.

The results from the plain carbon steel, Fig. 3, indicate that under the lower stress, the creep rate decreased rapidly during the first 500 hr after which it remained practically constant as the test was extended to 8500 hr. Under the larger stress the decrease, continued for the

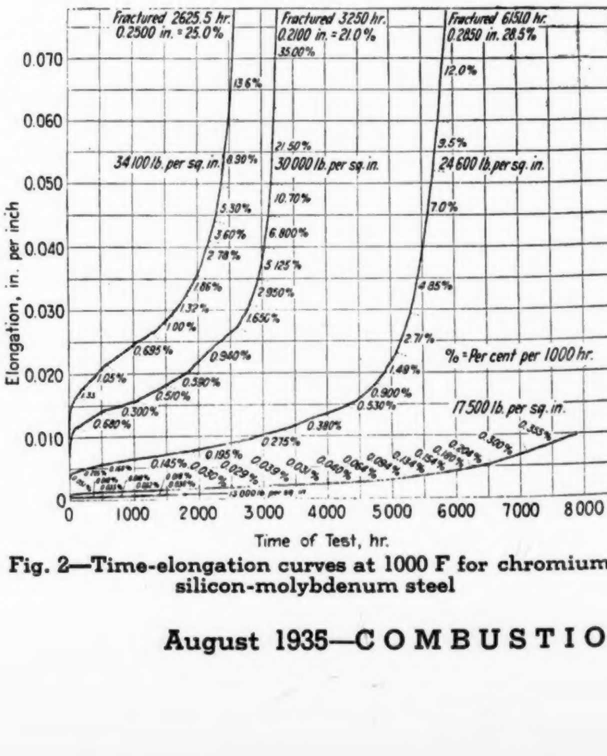


Fig. 2—Time-elongation curves at 1000 F for chromium-silicon-molybdenum steel

[1] *Proceedings*, Am. Soc. Testing Mats., Vol. 34, Part I, p. 1223 (1934); also 1935 Book of A.S.T.M. Tentative Standards, p. 1147.

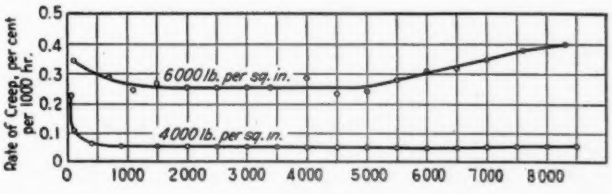


Fig. 3—Influence of time on observed creep rate for carbon steel at 1000 F

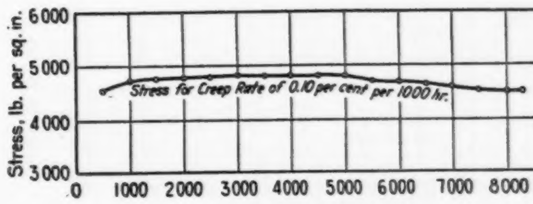


Fig. 5—Influence of duration of tests on reported creep stress for carbon steel at 1000 F

first 2000 hr, became constant over the period from 2000 to 5000 hr, and then increased for the remainder of the test. There is a possibility that the increase in creep rate after 5000 hr is not caused by the steel having entered the third stage of creep but is due to structural changes, such as spheroidization, having decreased the creep resistance. Additional results will indicate which of these two assumptions is correct.

The corresponding results for the chromium-silicon molybdenum steel are given in Fig. 4. As before, the creep rates decreased during the early portion of the tests, with the decrease being more pronounced, the greater the applied stress. The period over which the decrease occurred, however, varied inversely with the stress. With the two higher stresses, the minimum rate occurred at approximately 1000 hr, with the 24,600 lb per sq in. stress, at 2000 hr, and with the 17,500 lb per sq in. stress, at 4500 hr. In the tests which have fractured to date a very rapid increase in the creep rate occurred after a rate of 1.0 per cent per 1000 hr was passed.

There is a question as to whether deformation rates greater than 1.0 per cent per 1000 hr can be considered as creep. The word creep is usually reserved for slow rates of flow. On this basis it might be assumed that the creep characteristics predominate up to a rate of 1.0 per cent per 1000 hr and the short-time tensile properties above this rate.

Time Versus Creep Strength

In Figs. 5 and 6 the creep stress for the plain carbon and the chromium-silicon-molybdenum steels, respectively, are plotted against time. As before, the creep

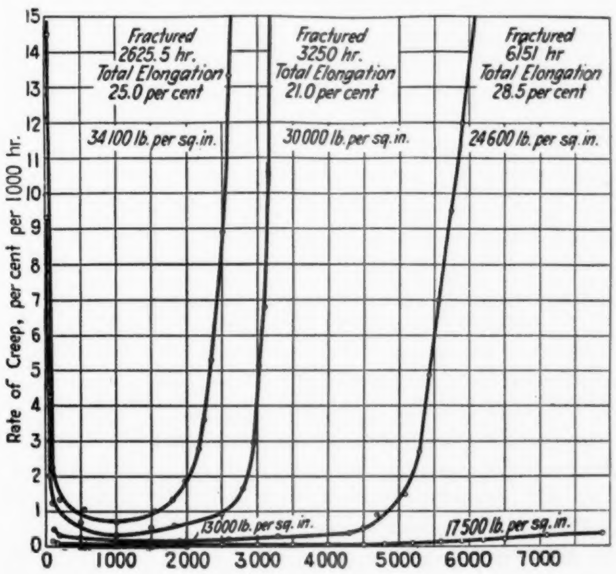


Fig. 4—Influence of time on observed creep rate for chromium-silicon-molybdenum steel at 1000 F

stresses at the various designated times are defined as the values which would have been reported had the tests been discontinued at that particular time. First considering the carbon steel, Fig. 5, the creep stress for 0.1 per cent creep per 1000 hr increased slightly for 1500 hr, then remained constant up to 5000 hr, after which it decreased for the remaining portion of the test. The observed variations in this value are not marked, however, as the minimum value is 4520 and the maximum, 4800 lb per sq in. It is also interesting to note that the 500-hr test gave a lower value than did the tests up to 5000 hr in length and further that this value agrees with that obtained after 8000 hr. In other words, for this particular steel at least, the 500-hr test is a more conservative indication of the true behavior under prolonged service at 1000 F than are tests up to 5000 hr in duration.

The corresponding variations in the creep strength of the chromium-silicon-molybdenum steel with time are given in Fig. 6. In this case stresses are included for creep rates of 0.1 and 1.0 per cent per 1000 hr over the entire periods of the tests, and also for a creep rate of 0.01 per cent for the first 2000 hr of the tests. As with the plain carbon steel, the stresses for the designated creep rates first increased as the time of testing was extended above 500 hr. In the case of the stress for the highest creep rate, the maximum occurred at 1000 hr, for the medium creep rate at 1500 hr, and for the lowest creep rate the stress value is still increasing at 2000 hr. Time exerts its greatest influence on the stress required for the maximum creep rate as the values range from 38,500 to 20,000 lb per sq in. The corresponding range in the stresses for the medium creep rate is from 22,500 to 16,700 lb per sq in. It is again to be noted that the 500-hr test is a more conservative indication of the true creep strength than is one of 1000 hr.

Metallographic Examination

In order to determine the influence of stress and time at 1000 F on the resulting metallographic structures, the fractured creep specimens, as well as the original material and the short-time tension specimens broken at 1000 F, were examined. Sections were selected at the fracture and at a distance of approximately $^3/_4$ in. from it, and magnifications of 100 and 1000 diameters were used.

The apparent grain size of the creep and tension specimens, was considerably smaller than that of the original material, indicating that at the section $^3/_4$ in. from the fracture the time at temperature and deformation conditions were such that refinement of the grain occurred. Also the grain size of the creep specimen became smaller and more uniform as the time for fracture was increased, or in other words, as the applied stress was decreased. The grain size of the short-time tension specimens was between that of the creep specimens subjected to stress

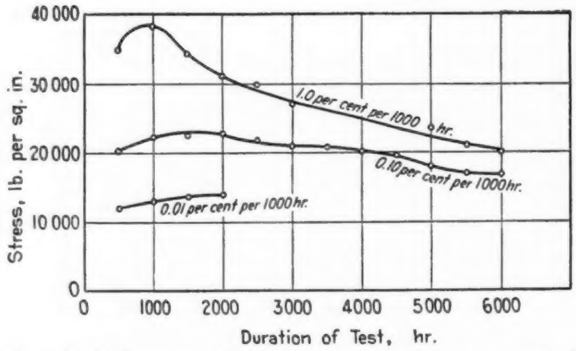


Fig. 6—Influence of duration of tests on reported creep stress for chromium-silicon-molybdenum steel at 1000 F

of 34,100 and 30,000 lb per sq in., indicating that stress (deformation) as well as time is a controlling factor on the resulting grain size.

The grains of the short-time tension specimens were also more distorted than those of the creep specimens. Since the sections examined were all at the same distance from the actual fracture, this indicates a more pronounced stress concentration in the short-time tension specimen.

The structure of the original steel was partially spheroidized and the fractured specimens did not show appreciable differences in the degree of spheroidization. Conclusive evidence is not, therefore, available as to whether spheroidization will occur at 1000 F under the given test conditions.

X-ray Examination

Various theories have been advanced as to the possible mechanism of creep and it was felt that an X-ray examination of the fractured specimens might shed additional light on this subject. Examinations were by surface reflection of the X-rays, produced in a tube equipped with a molybdenum target, from the specimen both at the fracture and at a section $^3/_4$ in. from it. The X-rays were passed both perpendicular and parallel to the axes of the specimens and both the outer surface and mid-section were considered.

The films indicate the original steel to be relatively free from strain. It is at least comparable in this respect to the commercially annealed steels usually encountered. The creep specimens contained more strain than the original structure, but no appreciable fragmentation of the grains had been produced. The short-time tension specimens were considerably strained and the grains were fragmented.

It is evident, therefore, that a difference does exist between the short-time tension and creep specimens in that the creep specimen shows strain without fragmentation, while the tension specimen shows both fragmentation and strain. Since the total elongation or deformation was approximately the same, there are two possible assumptions to account for the absence of fragmentation in the creep specimen. Either the process of deformation was such that fragmentation did not occur or else the time held at temperature was sufficient to remove the effects of this fragmentation.

Hardness Tests

All of the fractured specimens possessed a greater hardness, over the area considered, than the original steel, indicating that sufficient strain-hardening had occurred to produce a measurable effect. The tension specimen was harder than any of the creep specimens and the maximum observed hardness in the creep specimens decreased as the time necessary for rupture increased. These observed differences can again be accounted for either by a difference in the deformation characteristics or by the annealing effect of prolonged time at 1000 F.

Conclusions

Extended-time creep tests conducted at 1000 F on plain carbon steel and chromium-silicon-molybdenum steel, as well as metallographic, X-ray and hardness examinations of the fractured specimens allow the following conclusions:

1. In all the creep tests, the rate of creep decreases and thus the creep strength increases during the earlier periods of the test and the magnitude of the changes, for the given temperature, depends both upon the steel and the stresses being considered. If the stress is sufficiently great, the creep rate will increase after a certain time and the time required for this change varies inversely with the stress.

2. The reported creep stresses will, therefore, vary depending upon the length of time the tests are conducted. In the case of the carbon steel at 1000 F the amount of variation was not excessive. The changes were, however, more pronounced with the alloy steel due to the considerably greater stresses employed.

3. The ability of relatively short-time creep tests (500 to 2000 hr) to prophesy the behavior under more extended time periods varies, for the given temperature, with the steel considered. With a steel in which the net strain-hardening effect is slight, such as the plain carbon steel in this case, the time factor is not of great importance and a test of 500-hr duration gives a good indication of the load-carrying ability for periods of several thousand hours. For other cases in which the resulting strain-hardening effect is more pronounced, such as with the alloy steel, the reported values vary considerably over the period of 500 to 2000 hr. In both of the cases considered, the 500-hr test gives lower creep strength values than does the 1000-hr test and also values which correspond more closely with those obtained from tests of several thousand hours duration. The results would appear to indicate, therefore, that at least in the two cases considered, the 500-hr test is a more conservative criterion than the 1000-hr test.

4. The assumption ordinarily made that a creep rate of 0.10 per cent per 1000 hr represents a creep rate of 1.0 per cent per 10,000 hr is in consequence open to question, at least for some steels. Indications are that for the plain carbon steel this hypothesis may be approximately true but for the chromium-silicon-molybdenum steel this relationship was not found.

5. The fact that a specimen enters the third stage of creep does not necessarily imply that it will fail in a short time.

6. The time required for rupture influences the resulting ductility values but not in a uniform manner. The fractured creep specimens of the chromium-silicon-molybdenum steel all possessed a lower ductility than that obtained from the short-time tension test at the same temperature, but the variations in the values of the

creep specimens were not proportional to the time required for fracture. Neither were the changes of sufficient magnitude to cause undue alarm.

7. On the basis of the metallographic examination, structural changes were produced during both the tension and creep tests. All of the fractured specimens possessed a smaller grain size than the original steel and the grain size of the creep specimens became smaller, the greater the time required for rupture. Results also indicate that no appreciable spheroidization occurred during the tests. The findings do not permit too definite conclusions in this respect, however, since the original structure was partially spheroidized.

8. The X-ray examination revealed a difference in the apparent deformation characteristics. The original steel was relatively strain free, the creep specimens were strained, while the short-time tension specimen was not only strained but considerable crystal fragmentation had occurred.

9. A greater degree of strain-hardening was evident in the short-time tension specimens than in the creep specimens. The maximum hardness of the creep specimen decreased as the time required for rupture was increased.

10. The changes observed from the metallographic, X-ray and hardness examinations may be accounted for either on the assumption of a difference in the mechanism of deformation in the short-time tension and creep specimens, or that, in the case of the creep specimens, the time held at temperature was sufficient to remove certain of the effects of the deformation.

Acknowledgments

The authors desire to express their appreciation to The Timken Steel and Tube Co. for their financial assistance which has made these investigations possible and for their permission to publish the findings. Particularly do they wish to express their gratitude to F. J. Griffiths, H. H. Timken, Jr., W. H. Wiewel and K. B. Bowman.

Dramatizes Growth of Electricity

At a conference of more than four hundred executives of the General Electric Company and its affiliates from all parts of the world, held at Schenectady on July 15 to 17, a "Formula of Progress" was dramatized by the use of motion pictures, oral presentations, and special charts with synchronized sound and lighting effects. These illustrated how increased efficiency in productive activity has contributed to American progress.

Statistics were presented to show how the increase in the efficiency of generating, distributing and utilizing electricity has reduced its cost and how this lower cost makes it possible for the nation's industries to lower their costs.

It was shown that if the present 57 billion kilowatt-hours of fuel-generated electricity in this country were produced at 1890 efficiency, it would require 280 million tons of coal per year to produce it, instead of the 41 million tons now used.

The fuel saving due to increased generating efficiency, however, has made more kilowatt-hours available for more people, and this saving over 1890 conditions, when expressed in terms of real wealth, has a dollar value of $2^1/_2$ millions a day.

REVIEW OF NEW BOOKS

Any of the books reviewed on this page may be secured from Combustion Publishing Company, Inc., 200 Madison Ave., New York

Air Conditioning and Engineering

This exhaustive treatise on the technique of the conditioning and mechanical movement of air has been prepared by the Engineering Staff of the American Blower Corporation and the Canadian Sirocco Company, Ltd. The material has been selected and arranged with a view to providing a ready reference and convenient handbook for engineers having to deal with problems involving air flow and the application of air to ventilating, cooling, etc.

The book is divided into two sections, the first dealing with fundamental engineering information, charts, tables and other data, and the second with equipment, including dimensions and capacity tables.

Among the subjects treated in Section I are heat and steam, the laws of air flow and methods of measurement, ducts and their arrangement, fans for ventilation and for mechanical draft, fan drives, dust collection, humidifying and cooling, process drying and refrigeration.

There are in all 332 pages, 8 × 11 in., very fully illustrated and numerous working curves; heavy fabricoid binding. Price $5.00.

Standards on Refractory Materials

In addition to all of the twenty-one specifications, test methods and definitions standardized by the American Society for Testing Materials through the work of its Committee C-8 on Refractories, this publication includes the Manual on Interpretation of Refractory Test Data, detailed information on the standard samples of type refractory materials and reports of extensive industrial surveys showing the service conditions of refractories in outstanding consuming industries.

The specifications cover clay firebrick for various uses, refractories for the construction of incinerators, ground fireclay, and quicklime and hydrated lime for the manufacture of silica brick.

Included in the standard methods of testing which are given are the following: porosity and volume change; particle size of ground materials; panel test for resistance to thermal and structural spalling; permanent linear change; test under load at high temperature; softening point, high-temperature heat insulation and chemical analysis of refractory materials.

Accurate investigation of refractory materials is difficult unless competent methods are used to analyze and report the groups of data developed. The Manual on Refractory Data, which is given, evaluates the methods of interpretation. First issued in 1932, the current Manual is extensively revised and simplified.

To help maintain accuracy in the chemical methods of analysis, a series of standard samples of type refractory materials has been developed in cooperation with the National Bureau of Standards and a large number of laboratories. The composition of these samples is given in tabular form.

It has been essential to have adequate information on the conditions under which refractories are used in manufacturing processes. Comprehensive surveys have been made of such conditions in outstanding consuming industries, including the following: Open-Hearth Practice, Malleable Iron Industry, Copper Industry, Lead Industry, By-Product Coke Ovens.

This pamphlet contains 143 pages, size 6 × 9; heavy paper cover. Price $1.00.

Coal and Coal Products

Compiled by F. R. Wadleigh

A bibliography of books and articles relating to coal and to coal's principal products has been prepared and published by F. R. Wadleigh, consulting engineer of Washington, D. C., who was formerly chief of the Coal Division of the Department of Commerce, at one time associated with the Bureau of Mines, and Federal Fuel Administrator during 1922–1923.

This book of 63 pages contains not only a list of books and articles in the English language concerning coal, but also tabulates articles dealing with coal and related subjects, and similarly the publications of societies and technical institutes and bulletins and reports of various universities and colleges. The proceedings and other publications of the American Institute of Mining and Metallurgical Engineers, American Society of Mechanical Engineers, American Society for Testing Materials, American Mining Congress and the American Chemical Society are appropriately listed, as well as the reports of various commissions on coal in the United States and Great Britain.

Copies may be obtained from F. R. Wadleigh, 1026—15th Street, N. W., Washington, D. C. Price $1.00.

Dissolved Oxygen in Boiler Feedwater

By M. C. Schwartz, Ph.D.

This pamphlet issued by the Louisiana State University Press, Baton Rouge, La., describes a refined technique for the determination of dissolved oxygen as developed at the Louisiana Steam Generating Corporation's laboratory. The method is recommended for oxygen concentrates under 0.5 ml per liter. Section II of this 46-page pamphlet is devoted to a selected bibliography on the determination of dissolved oxygen in water. Copies may be purchased from the Library, Louisiana State University, for 50 cents.

Statistical Analysis of Boiler Accidents

By J. P. H. de WINDT, Nat'l. Bureau of Casualty & Surety Underwriters

At the recent Annual Meeting of the National Board of Boiler and Pressure Vessel Inspectors, in Chicago, Mr. de Windt described the statistical plan maintained by the National Bureau of Casualty & Surety Underwriters whereby data concerning accidents and losses are collected regularly from the insurance companies as a means of improving experience. The data in the paper, from which excerpts are here given deal with boiler losses for 1932, 1933 and 1934 and are classified according to the several classes of boilers.

THIS Statistical Plan is so designed and operated that the companies may know at any time the amount of earned premium that any particular type of object is producing, the total number of objects insured, what it costs to inspect the various classes of objects in different localities, the amount of the losses and the accident frequency on the various types of objects and also, from the standpoint of accident prevention service, the initial broken part and the cause of accident.

From the standpoint of the inspector and of the accident prevention service, the most important information to be obtained from this statistical plan is with reference to the kinds of objects that are producing accidents, and particularly the record of initial broken parts and the causes of failure. This important information is reviewed periodically by the insurance companies and they vary their inspection procedure to meet changing conditions which may be producing accidents, the frequency of which we would have no broad knowledge of if it were not for the statistical plan.

The information in this paper with respect to losses was obtained on a special call to the companies for statistical data in connection with boiler losses for the calendar years 1932, 1933 and 1934, but, due to the limited time available, not all of the companies could get together their report and the figures, therefore, are based on about two-thirds of the boilers that are insured by all of the companies doing a boiler insurance business.

The summary shows a total of 4585 losses amounting to $1,343,364 for all states and for all types of objects. Comparing this with the objects insured for all states, it is found that there are 5.2 accidents per year for every 1000 objects insured. It is of interest to note that there were only 132 losses over $1000 which is about 3 per cent of the total; but such losses amounted to $460,588, which is 34.3 per cent of the total.

In connection with boiler insurance, there are numerous types having different characteristics and hazards. These have been classified in accordance with the following types:

- I. Steel boilers—15 lb or less (steam); and hot-water heating or supply boilers.
- II. Fire-tube boilers—over 15 lb (steam).
- III. Water-tube boilers—over 15 lb (steam).
- IV. Track locomotive boilers (steam).
- V. Cast-iron boilers—excluding cracking of sections or other parts.
- VI. Cast-iron boilers—cracking coverage.
- VII. Miscellaneous pressure vessels, including tanks, digesters, economizers, refrigerating systems, piping and other fired or unfired vessels (not otherwise classified).

As would be expected, the accident frequency varies greatly for these types. Analysis of the statistical data develops that in connection with low-pressure boilers of the kind classified as Type I, there is only one accident per year for every 1000 objects. For high-pressure fire-tube boilers, the accident frequency is twice as great, being two a year per 1000 objects; and for high-pressure water-tube boilers, it is 7.8 accidents per 1000 objects, mainly on account of more frequent tube losses. For track locomotive boilers, the accident frequency is 1.3 per thousand. In connection with cast-iron boilers, cracking coverage is optional and the premium for such coverage is in addition to and much higher than the premium for explosion coverage alone. Type V above includes all insured cast-iron boilers and the experience applies only to losses under explosion coverage; Type VI includes only those boilers for which cracking coverage is provided (about 50 per cent of the total number) and the experience applies only to losses from cracking of sections or other parts. It is particularly interesting to note that the accident frequency is only 0.5 for explosion coverages but is 83 times as great for cracking (41.7 accidents per year for every 1000 objects, or about one in every 24). For the remaining pressure vessels, included above as Type VII, the accident frequency is 1.5 per thousand.

Analysis of losses by types of objects also shows quite a variation in the average amount of loss per accident. As would be expected, high-pressure boiler losses are much larger than for low-pressure boilers. For low-pressure steel boilers the average loss amounts to $112; for high-pressure fire-tube boilers $331; for high-pres-

sure water-tube boilers $408; and for track locomotive boilers $434. For cast-iron boilers, the average explosion loss is $173, whereas the average cracking loss is $231. Cracking losses not only occur very frequently but are large, one loss sometimes amounting to as much as two or three thousand dollars. The average loss for the miscellaneous group is $533, consisting of many losses smaller than the average and a few much larger (28 losses of over $1000, averaging $6440). The average loss for all types is $293.

Considering all types of boilers and pressure vessels, it is found that 83.8 per cent of the insured objects are located in states having representation on the National Board of Boiler and Pressure Vessel Inspectors but that the accident frequency is only 4.9 per 1000 objects, as compared with 6.7 for non-represented states.

Initial Broken Part

The special call for statistical data has developed some interesting information regarding the initial broken part, as respects each of the seven types previously mentioned. A few of the facts are presented below:

Type I—For low-pressure steel boilers, tube losses accounted for 46 per cent of the total. The remaining losses were made up of shell plates and drum heads (11 per cent), furnace and firebox sheets (10 per cent), tube sheets and steel headers (4 per cent) and miscellaneous (29 per cent).

Type II—For high-pressure fire-tube boilers, losses on blow-off piping amounted to 27 per cent, about the same as for shell plates and drum heads (26 per cent). The remaining losses were made up of furnace and firebox sheets (15 per cent), tubes (14 per cent), tube sheets and steel headers (7 per cent) and miscellaneous (11 per cent).

Type III—For high-pressure water-tube boilers, tube losses accounted for 58 per cent of the total. The remaining losses were made up of cast-iron tube headers (18 per cent), superheaters and reheaters (8 per cent), water walls or screens (3 per cent) and miscellaneous (13 per cent).

Type IV—For track locomotive boilers, 58 per cent of the total losses were on furnace and firebox sheets, 14 per cent on tubes and the remaining 28 per cent miscellaneous.

Types V and VI—Cast-iron boiler losses, as would be expected, are practically all in connection with cast-iron sections, only 1 per cent being otherwise classified.

Type VII—Inasmuch as this group includes all piping, as well as various types of fired and unfired pressure vessels, the piping losses predominate (53 per cent of the total). Losses on shell plates and drum heads amount to 16 per cent, tube losses 7 per cent, cast-iron parts 5 per cent and miscellaneous losses 19 per cent.

Description of Certain Large Losses

It was previously stated that 3 per cent of all losses were for over $1000 and accounted for 34 per cent of the total payment. Suppose we describe a few of these large losses.

1. A 72-in. horizontal tubular boiler located in a cotton seed oil plant in North Carolina exploded due to an accumulation of scale on the bottom of the shell. Six

employees were killed and nine injured. The brick power house was demolished, one-half of a two-story mill building was knocked down and there was considerable damage to expensive mill machinery. The boiler was ten years old at the time of the accident and was not built under Code requirements. Total property damage was about $45,000.

The investigation after the failure disclosed that, due to a storm, the character of the water in the river from which the feed was being taken, had been so changed that it contained considerable fine sand and bog material, not ordinarily present in the feedwater. As the cleaning periods were infrequent, enough of this material accumulated on the lower part of the shell to cause overheating which resulted in two rather large bulges. A rupture apparently started in the apex of one of these bulges, which extended through the other bulge, thus causing a sudden failure of the entire sheet. The evidence was that the boiler had been filled with water to the normal level, which contributed to the violence of the explosion.

2. In a paper manufacturing plant, located in Indiana, the "blind" head of a mud drum on a Stirling water-tube boiler ruptured, due to corrosion. One man was killed. The boiler was twenty-eight years old at the time of the accident. Total property damage about $25,000.

3. Another water-tube boiler explosion occurred when a lap seam failed in the rear upper drum of a Stirling type boiler only a short time after it had been reinstalled. The boiler was completely wrecked, the adjacent boiler was seriously damaged and the boiler house was demolished. Three men were injured, but not seriously. The total property damage was about $17,000. It is interesting to note that this boiler, which was about twenty years old, had, several years before, been discontinued from service in another plant on account of a badly corroded mud drum head and thin tubes. The boiler was purchased by the present owner after having been previously inspected and, before being installed, new tubes and new mud drum heads were fitted. After erection, the boiler was tested hydrostatically, during which test the inspector noticed leakage along the seam which later failed He had one of the rivets in this seam removed for an examination of the rivet hole but found nothing suspicious. An examination of the rupture after the explosion clearly showed that the initial crack did not extend through the rivet hole from which the rivet was removed, but did extend through a number of the adjacent rivet holes in that seam and the existence of the crack probably would have been disclosed had more rivets been removed. It is obvious from this case that the reinstallation of old second-hand boilers cannot be too strongly discouraged and they should be subjected to a better examination than is afforded by the usual methods of inspection.

4. A piping loss with unusual results occurred in a greenhouse in New Jersey, the escaping steam causing damage to valuable orchid plants. The accident was due to the failure of an expansion joint caused by water hammer when the steam was turned on too quickly. There were 1118 plants totally destroyed and 226 plants partially damaged. The total property damage was about $11,000.

Some Notes on PATENT LAW for ENGINEERS

By LEO T. PARKER
Attorney at Law, Cincinnati, Ohio

The author answers some questions as to ownership of patents by employee or employer, and gives specific suggestions that should aid the inventor in protecting his claims through maintaining complete records of his work, filing at the proper time and in proper form, and including a complete description. Decisions of the courts are cited to cover the points discussed.

FREQUENTLY, engineers, who are responsible for the design and operation of plants, are confronted with serious questions involving patents. For instance, several engineers during the past several months have asked the question: Suppose that while I am working at my regular work on a salary that I conceive and perfect an invention. Can I file an application and have the patent issued in my name, or can my employer claim ownership to the patent?

The old patent decisions held that the inventor was the sole owner of all patents applied for and issued in his name although the invention was perfected on the employer's time and with the use of the employer's equipment and tools. (*119 U. S. 226*).

However, it is important to know that the new patent law is different. In fact, a quite recent United States Supreme Court decision overruled the old decisions and established the present law that if a patent is granted in the name of an employee, and the patent is on an invention conceived, experimented and perfected on his employer's time while he was being paid to invent things, the employer is the legal owner of the patent.

Of course, convincing testimony must be introduced before a Court will issue an order requesting the Patent Office to transfer the title of an application already issued from the name of the inventor to the employer. However, under the above-mentioned circumstances the employer is entitled to full and complete ownership of the patent.

On the other hand, although an engineer is employed and paid to perform certain duties during specified hours the employer is not entitled to the ownership of a patent which the employee conceives and perfects while he is off his regular duty. This is true because an employer has no statutory rights or common law rights of ownership in his employee's patent, if the invention is perfected on the employee's own time, and where no contract exists between the employer and the engineer by which the latter agrees to assign all patents to his employer.

How to Protect Invention

Another question often presented by engineers is: How can I protect my invention with safety while I am experimenting, without incurring the expense of actually filing an application for a patent?

It is well established law that engineers may with certain security protect themselves against loss or theft of their ideas while the inventions are in the course of experimentation. On the other hand, the rules as established by the recent higher Courts on this subject must be carefully followed during the experimentation or the inventor may lose his legal rights to obtain a patent.

A complete review of leading higher Court cases disclose that an engineer may forfeit his right to a patent on his invention, under the following circumstances:

(1) If another person files an application for a patent on the device, and he was the first inventor; (2) if another person invents the device after the original inventor, but files his application for a patent before the true inventor; (*3*) if the inventor files an application for a patent, but fails to prosecute his case in the United States Patent Office within six months after the first answer is received from the Patent Office; (4) if the original inventor delays from six months to three years in filing an application for a patent after the invention is perfected so that it actually will operate, although it is crude; (5) if the inventor files an application for a patent before his invention is actually operative; (6) if the inventor fails to keep records and drawings properly dated and witnessed to establish his priority rights during the experimental stages of the invention, in the event another files an application for a patent; (7) if the inventor uses in public, sells or advertises the invention for two years before filing an application for a patent.

Another important rule of the law is that the United States will grant a patent to the first inventor who conceived, experimented, perfected and attempted to patent the invention. Therefore, the importance of inventors maintaining legal records of the conception and perfection of an invention is quite apparent.

Moreover, it is important for inventors to understand thoroughly that the legal status of an application for a patent is not, as many persons seem to believe, an absolute protection against others filing applications for patents on the same invention.

In other words, the mere fact that a person is first to file an application is not assurance that he will obtain a patent. This is true, contrary to the opinion of the majority of persons, because an inventor may be entitled to a patent although he files an application *after* another person has secured the patent. The government will revoke a patent issued to a person who is not the real inventor. Therefore, although an engineer obtains a patent he is not positively certain that he shall retain it, unless he has properly signed, dated and witnessed records to prove that he was the original to conceive and perfect the device.

Sketches and Records Important

Records of experiments should always be made with pen and ink, and should comprise sketches and written descriptive matter so complete that persons who are familiar with mechanism, or the science to which the invention belongs, may understand the invention. Moreover, each page of the records should be dated and the sketches, description and explanations of each experimental test should be included on the *same* sheet.

Where two inventors claim ownership to the same invention, both may testify as to their conception and perfection of the inventions, but this testimony is not convincing unless *dated* sketches having written descriptions, with testimony of witnesses, are introduced.

However, an engineer who had *perfected* an invention should not delay in filing an application for a patent. Delay may result in loss of his rights to obtain a patent, if another inventor is diligent and files his application immediately after perfecting the same invention.

For illustration, a recent Court refused to grant a patent to an inventor who was first to invent a device, but last to file an application for a patent. This Court stated the following important law:

"It is the settled doctrine of the Court of Appeals for the District of Columbia that when an inventor perfects and reduces to practice an invention, and fails for an unreasonable period to take steps to give it to the public, and until someone else has independently invented and patented it, the earliest inventor forfeits his rights to a patent against the later inventor. *83 O. G. 155, 84 O. G. 147, 87 O. G. 516, 88 O. G. 191.*"

If Inventor Files Own Application

Still another question frequently asked by engineers is: Can I file my own application for a patent without paying a lawyer, as I can make the drawings and I have heard that it is not necessary to employ an attorney?

It is true that the United States Patent Office "Rules of Practice" permits inventors to file their own application for patents. However, only those experienced in patent matters and procedure should attempt to do so, because the Government will not attempt to point out why or how a patent application should be written to protect the inventor. Moreover, the "claims" in an application are *strictly* construed by the Courts, and an invention which may be basicly new, and upon which a *very broad* patent can be secured by a patent lawyer, may be valueless to an inventor if the patent is obtained by any person who is not trained in patent law and subsequent procedure. Also, this rule is applicable to lawyers who are inexperienced in patent procedure. In some instances, inventors who are not certain about the value of their inventions, or who are short on funds, may prepare and file their own applications, which later *may be revised by competent lawyers.*

It is important to know that from a legal standpoint a patent application consists of drawings made with India ink on two- or three-ply bristol board, size 10 × 15 in. The specification of the application is a complete description of the invention with numerals on the drawings which are referred to in the specification to indicate clearly the various parts. At the end of the specification the "claims" include all basic features of the invention.

At the time an application for a United States patent is prepared the drawings, specification, petition and oath with the first government fee of $30 is sent to the Commissioner of Patents, Washington, D. C., and $1.00 for each claim over the twenty which are allowable without additional fee.

The application is examined by the examiner of the division in which the invention is classified. If he fails to find a similar invention he notifies the inventor, and allows the claims.

EQUIPMENT SALES

Boiler, Stoker, Pulverized Fuel

As reported by equipment manufacturers of the Department of Commerce, Bureau of the Census

Boiler Sales

Orders for 91 water-tube and h.r.t. boilers were placed in June

	Number	Square Feet
June, 1935	91	197,687
June, 1934	96	209,251
January to June (inclusive, 1935)	467	1,524,788
Same period, 1934	436	1,245,058

NEW ORDERS, BY KIND, PLACED IN JUNE, 1934–1935

Kind	June, 1934		June, 1935	
	Number	Square Feet	Number	Square Feet
Stationary:				
Water tube	43	141,166	40	129,899
Horizontal return tubular	53	68,085	51	67,788
	96	209,251	91	197,687

Mechanical Stoker Sales

Orders for 180 stokers, Class, 4* totaling 34,721 hp were placed in June by 68 manufacturers

	Installed under			
	Fire-tube Boilers		Water-tube Boilers	
	No.	Horsepower	No.	Horsepower
June, 1935	128	16,434	52	18,287
June, 1934	120	15,361	52	19,318
January to June (inclusive, 1935)	530	72,448	251	96,821
Same period, 1934	519	68,023	219	87,553

* Capacity over 300 lb of coal per hr.

Pulverized Fuel Equipment Sales

Orders for 5 pulverizers with a total capacity of 16,540 lb per hr were placed in June

STORAGE SYSTEM

	Pulverizers				Water-tube Boilers		
	Total number	No. for new boilers, furnaces and kilns	No. for existing boilers	Total capacity lb coal per hour for contract	Number	Total sq ft steam-generating surface	Total lb steam per hour equivalent
June, 1935	..	..	..	....	..	....	......
June, 1934	..	..	..	....	..	....	......
January to June (inclusive, 1935)	..	..	..	....	..	....	......
Same period, 1934	2	1	1	46,000	*	*	*

DIRECT FIRED OR UNIT SYSTEM

	Pulverizers				Water-tube Boilers		
June, 1935	4	4	..	15,940	4	19,191	180,000
June, 1934	4	4	..	12,400	4	16,000	138,000
January to June (inclusive, 1935)	52	33	19	255,060	44	256,059	2,304,780
Same period, 1934	31	22	9	252,610	23	208,475	2,144,700
					Fire-tube Boilers		
June, 1935	1	..	1	600	1	1,500	5,500
June, 1934	..	..	..	.....	..	.....	......
January to June (inclusive, 1935)	3	..	3	3,300	3	6,130	32,500
Same period, 1934	4	..	4	4,800	5	7,500	41,000

* Data not available.

STEAM ENGINEERING ABROAD

As reported in the foreign technical press

Pipe Joints and Caustic Embrittlement Being Investigated in England

On behalf of the Institution of Mechanical Engineers and the Department of Scientific Research, The National Physical Laboratory (Great Britain) has undertaken an investigation of pipe joints for high-pressure, high-temperature service. The experimental work is being directed toward the maintenance of tightness in flanged joints under purely elastic conditions, to the composition, design and performance of packing materials, to the creep characteristics of various types of nutted stud bolts, and to the measurement of bolt and flange deformation in a full-scale installation of 8-in. pipe that can be subjected to steam pressures up to 2000 lb per sq in. and temperatures up to 1000 F.

Another investigation now in progress relates to the causes and prevention of cracking in boiler plate and to corrosion fatigue. Mild steel boiler plate, immersed in a solution of sodium hydroxide, has been subjected to repeated bending at about 96 F. Metallurgical examination of such material, tested in a 0.1 per cent solution of sodium hydroxide, has shown that the cracks produced are mainly transcrystalline. In certain cases intercrystalline failure has occurred while in others there was evidence of corrosion, sometimes with preferential attack in the vicinity of non-metallic inclusions. For the later experiments now being made, the strength of the solution has been increased to 10 per cent and the test specimens include not only boiler plate but also complete riveted joints. Evaporation from the bath and decomposition of the sodium hydroxide into sodium carbonate is greatly reduced by pouring a layer of liquid paraffin over the surface of the liquid—*Engineering*, July 19, 1935.

New Swansea Station Put in Service

The first section of the new 240,000 kw station at Swansea, the latest British power station constructed under the Grid System, was officially placed in operation on June 20. This initial section contains two 30,000-kw turbine-generators and four 240,000 lb per hr boilers operating at 650 lb pressure and 850 F steam temperature. A feature of this station is that it burns Welch anthracite duff in pulverized form. This fuel analyzes 6 to 8 per cent volatile, 14 per cent ash, 74 to 80 per cent fixed carbon, about 4 per cent moisture and has a heating value of 12,500 Btu per lb as fired. Hardinge ball mills are employed for pulverizing and provision is made for mill drying. A bin and feeder system, water walls and straight-shot vertical burners are employed, air being supplied to the burners at approximately 700 F. Dust and acids are removed from the flue gases by the Howden "Non-Effluent Water Process" which was described in the April 1935 issue of COMBUSTION. An account of the opening of the station and the reasons leading up to its construction is to be found in *Engineering and Boiler House Review* for July.

Balancing Back-Pressure Operation

Warme for May 18, 1935, describes the Sonnleither engine which is designed to facilitate the balancing of steam and power demands in back-pressure operation. The engine has a single cylinder and the steam on one side of the piston exhausts to a condenser whereas that on the other side exhausts to process or to the heating system. Cut-off on the end exhausting to process is controlled by a back-pressure regulator while that on the other is controlled in the usual way to meet the power demand. In order to compensate for wide variations in demand for back pressure steam and thus avoid an approach to single-acting operation at times, a heavy flywheel is provided. Maximum efficiency is said to be attained at approximately 0.9 extraction ratio.

British Power Station Extensions

The savings in generating plant capacity, which were rendered possible by the Grid System in England, have now been made up and it is again necessary to carry out a program of extension to meet the increased consumption of electricity. The full program to be inaugurated this year will aggregate 650,000 kw at an expenditure equivalent to around $36,000,000. Directions have already been issued for extensions totalling 500,000 kw to be in operation by the winter of 1937. Included in these extensions will be a 50,000-kw turbine-generator and three 200,000-lb per hr boilers for Walmannock (Glasgow); a turbine and boilers of like capacity for Barton; a 50,000-kw turbine-generator and two 250,000-lb per hr boilers for Hams Hall; a 30,000-kw turbine-generator and three 375,000-lb per hour boilers at Battersea; two turbine-generators and two 210,000-lb per hr boilers at Brimsdown; and units of slightly less capacity at Thornhill, Kirkstall, Neepsend, Longford, Croydon, Clyde Valley and Brighton—*Engineering*, July 12, 1935.

Use of Peat in Euorpe

In Germany, Finland, Lithuania, Esthonia, Italy, Hungary and Russia, the respective governments are actively encouraging the use of peat, of which these countries possess large resources, according to an article

(*Continued from page 37*)

in a recent issue of *Oel u. Kohle* which is reviewed in the July issue of *The Fuel Economist.*

The importance of peat in Germany lies in the fact that it represents about 40 per cent of the total energy resources of the country. The heating value of air-dried peat, containing 20 to 40 per cent water varies from 2900 to 4000 calories per kg. About half the peat produced in Germany is worked by hand and for the rest mechanical excavators are employed, the latter being best adapted to thick seams.

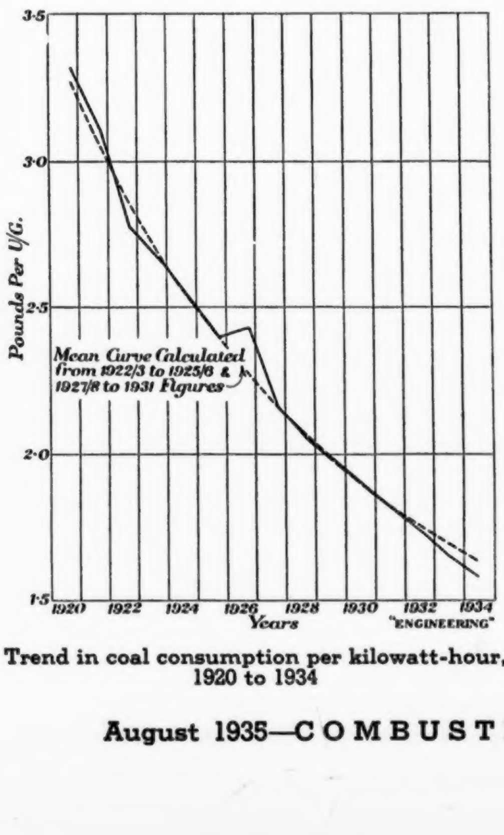
In Russia recent experiments have overcome the disadvantages of air drying by dewatering through pressure. Because of its colloidal properties, which tend to retain the water, the peat is first disintegrated and the fragments mixed with previously dried peat dust before the pressure is applied.

There are several different forms of peat, one of a powdery nature being extensively used as a humus-forming fertilizer, whereas other forms are used for fuel.

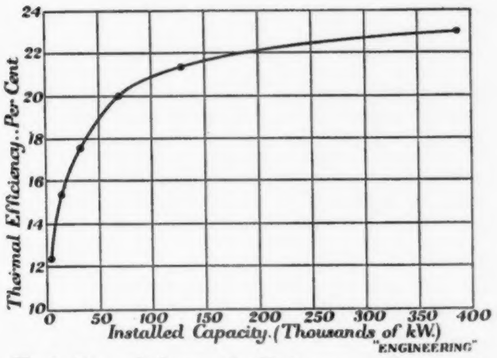
Industrial Power in England

In a paper on "Industrial Power Supply" before the National Electrical Convention at Bownemouth, England, reported in *Engineering* of June 28, the authors, Messrs. Hobson and Taite compare the power available per worker in England with that in the United States. In the former it is 2.81 hp whereas in the latter it is 5.38 hp. This is attributable to the fact that the introduction of labor-saving devices has proceeded more slowly in England. Despite this comparison the figure quoted for England has increased from 1.5 hp in 1907. In the earlier year only 6 per cent of industrial power consuming equipment was served by public electricity supply, whereas by 1930 this figure had grown to 35 per cent.

Commenting on the growth and the effect of the present Grid System, the authors presented the accompanying curves, showing the variation of thermal ef-



Trend in coal consumption per kilowatt-hour, 1920 to 1934



Variation of thermal efficiency with size of station

ficiency with the size of station and the trend in average fuel consumption for these electricity supply stations. The break in the curve of fuel consumption in 1926 was due to disturbances in the fuel supply and the necessity for using inferior coals. Taking the 1922 costs as an index of 100, the price of coal has dropped to 75 and the price per kilowatt-hour sold to 59.

Coal Used in Motor Transport

Steam automobiles in England, using coal as fuel, are rather widely employed, but in most other countries play no important part. It is estimated that in England at present, more than ten thousand steam-driven lorries are in operation and that they utilize approximately a million tons of coal annually—*The Fuel Economist* (London), July 1935.

Revised Boiler Rules for Marine Service

In view of the trend toward higher pressures and temperatures in marine service and the introduction of fusion-welded boilers, the Steamboat Inspection Service of the U. S. Department of Commerce has issued revised rules covering every type of boiler ordinarily used in marine work. These rules became effective July 1, 1935 and are issued in pamphlet form. Co-operating with the Bureau in the development of these rules were the following organizations:

The American Society of Mechanical Engineers, Boiler Code Committee,
The American Welding Society, Committee on Welding in Marine Construction,
The American Society for Testing Materials,
The American Standards Association,
Manufacturers' Standardization Society of the Valve and Fittings Industry.
The Society of Naval Architects and Marine Engineers,
National Council of American Ship Builders,
The American Association of Steamship Owners,
The American Bureau of Shipping,
The American Marine Standards Committee,
National Board of Boiler and Pressure Vessel Inspectors,
Malleable Iron Research Institute,
The American Uniform Boiler Law Society, and
The American Association of Steel Manufacturers.

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